Is the Latent Time in the Achilles Tendon Reflex A Criterion of Speed in Mental Reactions?

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IS THE LATENT TIME IN THE ACHILLES TENDON REFLEX A CRITERION OF SPEED IN MENTAL REACTIONS?

BY
GEORGE H. ROUNDS, Ph.D.

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G. H. R.

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CHAPTER I

The Time Factor in Mental Reactions: How the Present Inquiry Attacks the Problem

Is the latent time in the reflex a criterion of potential quickness in strictly mental reactions? The present point of attack on the problem of quickness of reaction is new—the search for a reliable criterion of what the individual can do. The problem of speed of reaction itself is old. The earlier experimental procedure was directed to the exact measurement of a definite type of mental reaction; this consisted in a simple movement of the hand in response to a definite stimulus such as light or sound. These reaction time experiments, beginning for the most part with Wundt and Donders and still going on, developed the general law that the time of the reaction varies inversely with the intensity of the stimulus. Another significant fact evolves; the time of reaction differs from one individual to another. These individual differences appear to be sheer speed differences—within certain limits; at least this is true for the simple reaction time. The precise determination of the individual time of reaction is far from simple. There is the stimulus to attend to; the movement one is about to make; the strength of the stimulus. When a man reacts to a light stimulus he exhibits a certain quickness of reaction; when light and sound stimuli are summed his reaction time is greatly reduced. Which is his normal speed level—if there is such a thing? What strength of stimulus will evoke this normal speed level? According to Ach the essential factor in determining the difference in reaction time in different individuals is the "observer's attitude toward the intention to react in its relation to the stimulus or to the movement."[1] This is far from being a simple direction to follow. When will one have—under what conditions—the essentially intrinsic speed level of a given individual and how will he know he has it? Perhaps there is a sort of quickness

[1] Quoted from Henmon: Archives of Psychology, number 30, page 30.

level which is preeminently characteristic of a given individual. This level is not a fixed point; it is rather a certain range of speed. Various factors quicken the individual speed of reaction. As just mentioned the summation of light and sound stimuli markedly reduces the time of reaction (JENKINS). Incentive and punishment likewise quicken the reaction; punishment appears to bring out more speed than incentive (JOHANSON). Distraction increases the reaction time in both trained and untrained subjects; apparently it is never overcome (EVANS).

These recent experimental results illustrate the present-day trends in exploring the subject of reaction time. The essential purpose of these studies is to get in touch with the individual speed ability and the factors which govern it. But reaction time experiments are not the only methods employed to get data on this problem. The fact of improvability brings individual speed ability to light. Subjects in one level of ability exhibit a high initial speed; those in another level exhibit a low initial speed—initial, *i.e.,* at the beginning of a practice period—. Given a definite practice period for all subjects; the subjects whose initial speed is high exhibit the greatest gains. Those whose initial speed is low do not even reach the initial speed of the other group; their relative gain is usually less. In other words, the speedy individual begins at a higher level and after a period of practice he exhibits a greater quantity of gain than the slow individual. This the general rule. If the material is simple, such as certain cancellation tests, the speedy individual approaches his maximum speed; consequently the slow individual may sometimes exhibit the greater gain (RACE).

The various tests, intelligence tests and others, bring out individual differences in speed. In the earlier testing, there was a rather strict time limit. There is a time limit at the present time, but the amount of time allowed is much more liberal. This is notably true in such a test as the MCCALL READING TEST. Somehow the notion creeps out that speed is something more or less external to "intelligence." The present trend is to isolate speed from other factors in mental ability and get at their relationships—if there are any really intrinsic ones. THORNDIKE suggests recently an analysis of ability into level, range and speed. Perhaps some day these three items in ability will be accurately measured, each independently of the other.

Other experimental data bring to light the fact of an optimal speed for each individual. For example, accuracy of judgment is related to the quickness in making the judgment. This is exemplified in judgments on lifted weights and length of lines. There is an optimal exposure interval, that is, an optimal rate in judging the weights; too long an interval or too brief an interval reduces the accuracy. The rate is specific to the individual function; it is similar when the functions are similar. An individual subject may be slow in one function but fast in another (GARRETT). In the more distinctly motor functions there is an optimal speed of movement at which the efficiency is maximal. Using an ergometer; to and fro movements of the arm; highly trained subjects; (1) work constant; very fast and very slow rates reduce the efficiency. It costs more to work the ergometer very slowly or very fast. There is an OPTIMAL rate; the efficiency is greatest at the median rates and differs in different subjects. (2) Rate constant; the subject soon finds his optimal rate for the specific work. Here again there is an optimal efficiency at about the median rate—median for the individual subject (CATHCART). Speed and efficiency are likewise related to the amount of effort. In general, the stronger effort is the most efficient; the stronger effort has the greatest optimal speed. The mechanical efficiency of a submaximal effort is always less than that of a maximal effort occupying the same time. In other words, the weaker effort is inefficient. One man at some definite speed exhibits the same efficiency as another man at another speed; there is a constant optimal efficiency over a rather wide range of speed (HILL).

What is the relation of quickness to intelligence? This question is being weighed in the balance at the present time. Given, for example, Spearman's theory of two factors in every mental performance; does speed or quickness operate as a factor independent of general ability? What is the relation of speed to the so-called "group" or specific factors? Is speed a group factor comparable to other group factors? Is it possible to have superior mental ability regardless of the rapidity of mental reaction? Are quickness and intelligence independent or interdependent? BERNSTEIN found no evidence of any such independent speed ability. Quickness does not appear to function as a group factor. Quickness and intelligence appear to be interdependent. PEAK and BORING reach similar conclusions.

They find a high correlation between speed in an intelligence test, score in an intelligence test and speed in reaction time. These correlations appear to depend on the time limits of the test; increasing the time limit destroys the correlation since the faster subjects have nothing to do in the additional time. Difference in speed appears in single test elements. Other observers have stressed what they call "speed" and "power." "Power" appears to mean the level of difficulty to which the subject can go. It will be remembered that THORNDIKE uses the word "level" as one of the factors in mental ability; range and speed being the others. HUNSICKER found that rate of work on the no difficulty level (speed elements) is related to the level reached in the difficult elements (power elements). A subject who exhibits a high rate of work may be expected to do a larger amount of the difficult elements. The correlations between the two types of reaction are indicative of a "relationship between the rate of mental work and the level of intelligence itself."

Other investigators have been concerned with what may be called the "content of speed." What makes one individual slower than another? This approach to the problem has to a considerable extent centered in the phenomenon of perseveration. It is known that a visual impression has an after effect. This after effect appears to be present also in the more distinctly mental functions. After an idea has lapsed from distinct consciousness, it may exercise an after—or secondary—function; it tends to rise again into consciousness. In other words, a psychical effect may continue after the cessation of the external stimulus. This unconscious perseveration may modify or hinder succeeding mental responses. According to LANKES and BERNSTEIN, perseveration is a factor in the speed of mental action. It varies in different individuals and, according to these observers, appears to be an inborn or native quality of the nervous system.

The observers mentioned in this review of recent experimental findings appear to have limited their inquiry to the direct study of more or less strictly mental reactions. Mental and motor tests and instruments were the usual materials in their hands. All the tests which they used exhibit both or either psychical and motor reactions. In all cases these reactions are learned reactions. There is no immediate learning of a given test. The relative and varying quickness of the

reaction depends on such factors as facility in the use of language; familiarity with all the items in a given situation such as a sentence completion test—all these and other factors PLUS some inherent factor of speed over which the individual has little or no control. It is precisely at this point that the present inquiry attacks the problems of speed in mental reactions. The situation is as follows:

1. *Does the nervous system of the individual exhibit a native quickness of activity? To what extent does this native quickness differ in different individuals?* Doubtless several plans might be worked out for the study of this problem. One might, for example, measure the chronological factor in the excitability of nerve tissue—the chronaxie, as it is called. Such a technique is by no means easy to handle in the human being. Furthermore, the resulting measurements, which exhibit the quickness of nerve action in a given individual, ought to be a representative sample of nerve action in the given individual. Some nerve fibers conduct more rapidly than others. The speed of performance in some single fiber or functional group of fibers might not be characteristic of the nervous system as a whole. One ought to isolate some more or less complex nervous mechanism which will exhibit a characteristic sample of the speed of nerve action in the given individual. The Achilles tendon reflex was chosen for this purpose. This neuro-muscular mechanism is already isolated in any individual; that is to say, when a stimulus is applied to the mechanism it responds as a unit. This reflex exhibits a speed of action which can be studied in a clear-cut and measurable form. Its speed of action appears to be inherent; it exhibits no learning. Furthermore, the speed of the reflex does vary. For example, its speed of action is distinctly slow in Myxedema. It correlates with the general sluggishness of mental action which characterises the individual in this condition. When thyroid substance is administered the speed of the reflex rises along with the rise in general mental quickness. In such an extreme illustration the speed of the reflex does run parallel with the speed of mental action (CHANEY).

Presumably the nervous system of a given individual can develop a certain range of speed. The reflex, for example, may run more slowly at some times; at other times, and in particular during some special stress, the inborn quickness or reaction may reach a high level for any particular individual.[2]

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[2] Experiments with strychnine illustrate this high level of response under special conditions (SHERRINGTON 2).

There is no attempt here to measure this possible range; one needs to keep it in mind as a possible source of error. It is assumed that in a given individual there is a more or less uniform, normal or basic quickness which characterises this or that individual. The optimal speed which appears to characterise an individual in many types of reaction supports and illustrates this assumption. Individuals differ in the speed with which they can do work or, more precisely, in the quickness of their reaction to a given stimulus. The slow individual can never, not even with the most extravagant burst of speed, reach the speed level of the quick individual.[3] In measuring the quickness of an individual one must not base the measurement on some supreme burst of speed nor on some extreme slowness. Given a condition where the individual is relaxed, quiet and free from disturbing influences which might accelerate or retard his speed of reaction; in such a condition the individual may be expected to exhibit a level of quickness which is particularly characteristic of him. The measurements which one secures during this condition will best represent the inborn quickness of nerve action which this individual possesses. In the present study these measurements are concentrated on the latent time of the reflex. There is considerable evidence that the latent time runs parallel with the rapidity of the reflex reaction in the contracting muscle; in fact a brief or a long latent time must mean a quick or a slow reflex reaction.[4] Further-

[3] Recent experimental results on improvability support this point of view. RACE concludes that the more superior the general intelligence the greater the improvability. The superior subject exhibits higher initial speed ability—at the beginning of the experiment; his gain is greater than that of the inferior subject. For example, a superior group shows an initial speed ability of 38.25; the average gain for this group is 26.25. On the other hand, the subjects of ordinary intelligence begin at a lower initial level and their gain is less than that of the superior group. For example, one group shows an initial speed ability of 13.875; their gain is 16. Here the slow subjects begin at a much lower level and their total gain does not bring them up to the initial level of the superior group (figures mean number of problems solved in a unit of time).

[4] CARLSON (*American Journal of Physiology*, 7:401 and 15:136) concludes that the most rapidly conducting nerve is connected with the most rapidly contracting muscle. LAPICQUE (L'excitabilite en Fonction du Temps) stresses "isochronisme du muscle et du nerf"; that is, when a nerve reacts rapidly, the muscle with which it is connected also reacts rapidly. SHERRINGTON (*Proceedings of the Royal Society*, 97B:519) reports that in partial inhibition where the stimulation of the inhibitory nerve and the excitatory nerve is concurrent, the latent time as well as the rapidity and amount of the muscle contraction are changed; the latent time is lengthened; the amount of the muscle contraction is less; the rapidity of contraction is less; the amount of these changes depends on the relative amounts of the inhibitory and excitatory stimuli. On the other hand, in the supramaximal reaction where presumably the capacity of the nerve and muscle approaches a limit, the latent time is markedly reduced; the amount of contraction is larger; the contraction takes place more quickly.

more, in conditions which call for an acceleration of speed the latent time is shortened; in conditions which call for a slowing of speed the latent time is lengthened.[4]

2. *What speed of mental action does the individual exhibit?* Quickness in mental reaction is exhibited in functions which have been acquired—learned. The essential program in this inquiry is to measure (1) the inborn speed of reaction which the nervous system reveals in the tendon reflex; (2) the speed in strictly mental reactions and (3) to compare the results in these two types of reaction. There is on the one hand a native inborn reflex arc; on the other hand there are various functional reactions which have been acquired or constructed during the life of the individual. It is true that the quickness in these learned reactions tells what the individual does when tested; at the same time this speed of reaction *now,* may tell nothing about the individual's real intrinsic speed ability or may give a very inadequate view of these abilities. The individual's learning is apt to be incomplete. One may find a wide range of these incomplete learnings even in such a simple, elementary mental reaction as crossing out "A" or adding two or three single place numbers. Such defects in learning may be entirely independent of native quickness which the individual may possess. If one were to measure these defects in learning, the result might be a normal curve of distribution both for different individuals in the same test and for the same individual in different tests of presumably equal difficulty. In other words, there may be a wide difference between the individual's inherent quickness and his acquired quickness in the performance of simple mental functions. *The latent time in the reflex may tell what the individual can do; it may be a criterion of his potential quickness in strictly mental reactions.*

CHAPTER II

The Reflex Mechanism; How It Is Set in Action; the Neural Arcs Which Cooperate to Make the Reflex a Unit Mechanism.

The peripheral components which make up this reflex arc are, (1) the Achilles tendon; (2) the Gastrocnemius muscle and, in some measure, other extensor muscles such as the Soleus. Both muscles, Soleus and Gastrocnemius, are attached to the Achilles tendon; these muscles are extensor in function—their contraction extends the foot. Each of these muscles has an abundance of short fibers and large areas for tendinous attachment; in the Gastrocnemius, the fibers pass diagonally downward to join the sides of the Achilles tendon at various levels. In the reflex reaction, the Gastrocnemius muscle appears to play the leading part. (3) The Internal Popliteal division of the Great Sciatic nerve; this nerve trunk—the Internal Popliteal—sends a branch to each of the two heads of the Gastrocnemius muscle and to the Soleus muscle. The nerve contains both afferent and efferent fibers. Its origin is in the Sacral plexus. The fibers within the nerve, which reach the Gastrocnemius muscle, appear to have their origin in I and II Sacral segments. (4) The Tibialis Anticus muscle and its connecting nerve, the Anterior Tibial; this nerve is a branch of the External Popliteal nerve. The fibers within the Anterior Tibial, which reach the muscle, appear to have their origin in IV and V Lumbar and I Sacral segments. The Gastrocnemius and the Tibialis Anticus are antagonists; the former extends while the latter flexes the foot.

The Achilles tendon reflex is a myotatic reflex—a stretch reflex; its normal or adequate stimulus is stretch or tension of the muscle; the muscle responds to stretch with active contraction. This reaction to stretch is not a direct contractile response; the muscle fibers do not respond directly and immediately to the stretch. Sever the motor nerve and there is no response. Nor is there any contraction when the afferent nerve supply is cut off. The contraction which follows the stretch stimulus is (1) *a reflex effect and* (2) *the source of the reflex is within the muscle itself*—the mechanical stimulation of certain receptors or end organs within the Gastrocnemius muscle. This reflex effect of stretch applied to the Gastroc-

nemius muscle extends to its antagonist, the Tibialis Anticus. Stretch of the extensor muscle does two things: it initiates contraction of the extensor and, simultaneously, lengthening of the flexor muscle. As the myotatic contraction of the extensor reaches a maximum of extension at the foot, the consequent stretch on the flexor unfolds a myotatic contraction of the Tibialis Anticus and, simultaneously, lengthening of the Gastrocnemius.[5] This interaction of the extensor and flexor muscles in the reflex is clearly exhibited in the relaxation period of the records secured in the present inquiry. The relaxation of the extensor muscle at the end of the individual response —single reflex reaction—is far from being a passive return to the starting point or base line. The contracting Gastrocnemius reaches a maximum of shortening; stays there briefly; then returns quickly to the initial condition. This quick return represents the cessation of its own contraction and the simultaneous contraction of its antagonist. The extensor lengthening runs parallel with the flexor contraction; the lengthening proceeds slowly when the flexor stretch is slow; rapidly when the flexor stretch is rapid.

The sharp tap on the Achilles tendon—the sudden increase in tension—initiates the reflex response. The mere fact of progressive increase in stretch progressively stimulates more receptors in the muscle. The reflex contraction increases as the number of active receptors increases; that is to say, slow stretch, progressively increasing, will eventually contract the muscle completely. The total amount of stretch at the end of any period of time determines the number of receptors in action and the consequent amount of contraction. In other words, given an end result—the complete contraction of the muscle and the full extension of the foot; *the stretch movement* which elicits this effect may consume a long or a short period of time; it may, for example, take place in 8 seconds or in .08 seconds. Therefore, when a considerable amount of stretch is concen-

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[5] This may be illustrated in a controlled experiment. Suppose, for example, stretch is applied to the knee extensor and maintained; a contraction of the extensor follows this stimulus. If, during this contraction of the extensor, the stretch stimulus being constant,—if during this constant and continued stimulus and reaction of the extensor, a stretch is applied to the knee flexor, there follows immediately a pronounced cessation of the reflex contraction of the extensor. This illustrates the sharp and vigorous effect which stretch stimulation of one antagonist has in overbalancing and even extinguishing the contraction of its opponent (SHERRINGTON, *Proceedings of the Royal Society*, 96B and 97B—1924 and 1925).

trated into a very short period of time, a large number of receptors respond nearly simultaneously and, in consequence, elicit a quick and complete contraction of the muscle. The sharp tap on the tendon does this very thing; the stretch which it elicits is sudden and rapid; many end organs are stimulated within a very brief period of time. In no case, however, is the stretch stimulus instantaneous as is the electrical stimulus; the stretch movement usually occupies several sigma of time; in the present experiment this time appears to be about 15 sigma. It should be noted that setting up the reflex response depends on a certain threshold value of the stimulus; the stimulus must excite a certain number of end organs in a very brief period of time. It is very likely that the stretch stimulus never excites all the muscle receptors not even with considerable amplitude of stretch (that is, unusual strength of stimulus which is conditioned by the velocity of the blow at the tendon) and short duration of the stretch movement. SHERRINGTON holds that the amount of the stimulus in terms of amplitude and quickness of the stretch rapidly reaches a maximum beyond which any further increase in the stimulus reveals no effect in the reflex response. (Proceedings of the Royal Society, 96B; see also FULTON, same Journal, 98B: 577.)

The reflex arc in the tendon reflex, which is the subject of this study, begins with the tap on the tendon. Muscle end organs, in response to this tap, set free afferent nerve impulses. These impulses enter the spinal cord through the corresponding posterior roots. *What next?* Is this tendon reflex a local spinal reflex? Does it represent the activity of one or two segments of the spinal cord?—those segments which belong to the Gastrocnemius muscle? Does the ascending limb of the reflex arc run from the posterior or afferent roots directly and immediately to the anterior or efferent roots of the same or adjoining segments?—this and no more? What becomes of the afferent impulses after leaving the muscle? What is the arc over which they travel back to the muscle and elicit a contraction of that muscle? PIKE insisted several years ago that "no independent proof has ever been adduced that the reflexes for the skeletal muscles in higher vertebrates occur through an arc involving the spinal cord alone when the whole central nervous system is intact." At present, attention is confined to the highest vertebrates; to an extensor reflex in the human being; to a reflex originating in the Gastrocnemius muscle.

There is positive evidence of a reliable experimental nature that this reflex arc runs beyond the limits of the spinal cord. According to SPIEGEL the most important prespinal center in this reflex arc is Deiter's nucleus; apparently other closely allied nuclei in the same region of the brain cooperate to more or less extent. But SPIEGEL is concerned with animals such as the dog or cat. In man it appears certain that some, at least, of the afferent impulses which the tap on the tendon sets in action pass up as high or higher than the mid brain. In animals the efferent pathway appears to be the vestibulo-spinal tract. It is known that in lesions of the Pyramids the reflex is disturbed; consequently the cortico-spinal tracts are concerned in the normal operation of the reflex.[6] Several arcs appear to cooperate to make the reflex a unit mechanism. There is the stimulation of the extensor muscle—the tap on the tendon. There follows the contraction of the extensor; cessation of contraction in the flexor; then contraction of the flexor antagonist during the relaxation period of the extensor and the return of the myograph lever to the base line. Very likely the Sympathetic nervous systems plays some cooperating part in the present reflex, but the available evidence is not secure enough to warrant any positive statement. Thus the tap on the tendon elicits a number of reflex reactions; some of these reactions are organised in—have their centers in—the region of Deiter's nuclei; others are organised in the mid brain. Very likely some part of the Cerebrum is a constant factor in the total reflex response. BREMER gives evidence that the Cerebellum is an essential element in the normal reflex response.[7]

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[6] It is interesting to note that the Plantar reflex is a Cortical reflex; the efferent limb of the arc is the Cortico—spinal tract. In the normal condition the response is flexor; when the cortico-spinal tract is injured, the response becomes extensor. MINKOWSKI studied the successive organisations of this reflex from the spinal to the cortical levels. During the first two or more years of infancy and in complete section of the spinal cord the reflex is extensor—A PURE SPINAL REFLEX. In the adult the organisation level has been shifted to the Cortex and the response is flexor in function. In certain pathological conditions the reflex center retreats to the spinal level. ROTHMANN found the "Beruhungs-reflex" totally absent in his "grosshirnlosen Hund."

[7] The experimental evidence which supports the positive conclusions in regard to the reflex arc in the Achilles Tendon reflex is as follows. (1) THE EVIDENCE DERIVED FROM THE EXPERIMENTAL STUDY OF THE DECEREBRATE PREPARATION. In the decerebrate condition the extensor muscle (quadriceps or gastrocnemius) is hypertonic; excessive rigidity is a constant feature; stretch of the muscle evokes contraction of the muscle; this contraction is reflex; the source of the reflex is in the muscle end organs; stretch is the adequate stimulus of these receptors; section of the afferent roots or section of the entire nerve trunk to the muscle abolishes

the reflex. The afferent nerve from the muscle is the only afferent channel for these impulses sent out by the muscle receptors. THUS THE REFLEX EVOKED BY THE STRETCH OF THE MUSCLE IN THE DECEREBRATE CONDITION ARISES WHOLLY IN THE GIVEN MUSCLE AND ENDS WHOLLY IN THE SELF-SAME MUSCLE.

THIS AFFERENT PATHWAY LEADS FROM THE GIVEN MUSCLE TO THE PRESPINAL CENTERS IN THE BRAIN STEM. Section of the posterior column or the direct cerebellar tract has no effect on the rigidity; section of the lateral column abolishes the rigidity on the same side; transection below or in the lower half of the bulb abolishes the rigidity—the limb immediately becomes flaccid; swings to and fro like a flail when set in action. Section of Deiter's spinal tract abolishes the rigidity on the same side. Momentary stimulation of this—Deiter's—nucleus or its fibers causes increase in the rigidity; massage of the muscle likewise augments the rigidity. The mechanism which subserves the rigidity in this decerebrate condition is distinct from the pyramidal tracts for (a) section of the lateral half of the bulb ABOVE the level of the decussation of the pyramids abolishes the rigidity on the same side; (b) transverse section of the lateral region of the same part of the bulb without interference to either pyramid abolishes the rigidity; (c) excitation of this region—lateral—of the bulb, reinforces the rigidity on the homonymous side. Activity in this reflex arc is primarily autogenic—arises in the muscle itself for (a) cooperation of the otolith organs and the neck receptors is not essential for the reflex; (b) ablation of the Cerebellum does not abolish the reflex. It is to be noted that SHERRINGTON uses the decerebrate preparation in his investigation of the myotatic reflexes; this myotatic reflex is a tonic or postural reflex; in decerebrate rigidity this reflex is abnormally accentuated owing to the loss of higher centers which normally cooperate in the reflex response. Furthermore, SHERRINGTON used the cat in his experiments; in this animal, as well as in the dog, centers essential for the maintenance of the rigidity lie exclusively in the brain stem; eliminate these centers and the limb immediately becomes flaccid. While these brain stem centers are indispensable links in the reflex arc or arcs which connect the muscle end organs with the muscle fibers, other centers are equally indispensable for the normal and regular operation of the reflex. In the decerebrate the activity of the reflex is abnormally accentuated; when the Red nucleus is intact; that is to say, when a reflex arc or arcs from the muscle through the mid brain—Red nucleus—and thence to the brain stem centers, and spinal centers (the Rubro-spinal tract, for example), are intact, the response of the myotatic reflex becomes approximately normal. Since these prespinal centers subserve the activity of the reflex in the dog and cat, the centers which subserve the activity of the same reflex in man cannot lie at a lower level than the brain stem and mid brain. The fact that lesions of the Cortico-spinal tract upset the reflex; the fact that the Plantar reflex is organised at the Cortical level in the adult human being; these facts point to the participation of centers even higher than the mid brain in the normal operation of the reflex.

(2) THE EVIDENCE DERIVED FROM COMPLETE TRANSECTION OF THE SPINAL CORD. There is total absence of reflex action below the level of the section; this "spinal shock" takes effect in the downward direction only; there is no upward spread; the upper limbs are not disturbed when the section is made at the appropriate level; the number of segments in the isolated spinal cord has no significance; that is, a single segment is fully as active or inactive when isolated as when intact with several other segments. In physiological transection of the spinal cord, the reflexes below the point of application of the saline solution disappear; the reflexes above this point are not affected; when the solution is absorbed the reflexes return to normal action. Freezing the cord evokes a similar loss of reflex action below the level of the injury. This spinal shock is much more severe in the monkey than in the dog or cat. In a monkey, immediately after transection of the cord, the limbs hang limp and flaccid; they swing to and fro like a flail when set in motion; this condition continues for days and even weeks; even after the shock appears to disappear

the reflex movement is slight and very erratic; it varies much from day to day and is easily exhausted through fatigue; the stimulus required to elicit a reflex is enormously large; yet the muscle fibers are responsive, for stimulation of the Pyramidal tract evokes the usual variety of movements.

Thus even after the period of shock is over, it is very difficult to set the reflex machinery going and keep it going. In the dog or cat, on the other hand, soon after the transection—minutes or hours—vigorous reflex movements can easily be obtained; the movements are more forcible, more prolonged, more readily obtained and less easily exhausted by fatigue than in the monkey. SHERRINGTON stresses the slightness of solidarity possessed by the isolated spinal cord in the monkey; the far greater independent vitality of the spinal cord in the dog or cat; it is a "great physiological contrast; a profound difference and chiefly quantitative. The dog differs less from the frog than the monkey from the dog, while the morphological gap between the dog and monkey is much less than that between the dog and frog." Spinal shock is much more severe in man than in the monkey. In man the tendon reflexes below the level of the injury are completely abolished for months and even years; the reflexes above the level of the injury are not affected. This spinal shock—the elimination of reflex activity below the level of the injury—is not due to changes in blood pressure nor to long continued inhibition; nor is the degree of the trauma the causal factor. Spinal shock is purely a nervous phenomenon; the essential factor is the rupture of the long conducting pathways in the spinal cord (SHERRINGTON, 1, 2, 5; PIKE; HUNTER and ROYLE; SPIEGEL; MAGNUS).

CHAPTER III

The Recording Apparatus; Is the Stimulus Constant? The Preliminary Set-up and Adjustments

The subject sits in a chair at a table. The table is a heavy one, but the legs are clamped to the floor to make sure that there is no movement. The subject's right leg rests in a wooden collar lined with leather and rubber to make sure of a maximum of comfort for the subject; the letter "a" on the diagram indicates this feature of the set-up. The frame which holds the collar is attached to the table. A screw attachment in the frame raises the subject's leg a suitable distance from the floor. The subject's sitting position is adjustable as to height; consequently the knee is horizontally level with the thigh. This adds to the subject's comfort and prevents any circulatory disturbances. The leg below the knee is held immovable through attachments at three points. (1) A piece of wood screws down from the top of the table to meet the patellar bone—"b," in the diagram; this prevents any upward movement of the leg. (2) Another attachment, "c," meets the front of the leg about half way between knee and foot. This is adjustable by means of a screw on either side of the leg; the screws are attached to the frame which supports the leg; this attachment prevents any forward movement of the leg. (3) Another attachment—"d"—meets the leg from the rear. A metal cup lined with a small bit of leather meets the enlargement of the tibia at the ankle; there is one cup on each side of the ankle at this enlargement. By means of a number of screw joints these cups are adjustable in several directions so that the cup is accurately and comfortably adjusted to the ankle. This attachment which thus meets the leg from the rear screws into the immovable frame supporting the leg. Thus the leg below the knee is firmly held in one position; the tap on the tendon does not move the leg in any direction. The ankle joint alone is free to move in its customary extensor and flexor directions. In other words, the stimulus sets up action in the reflex mechanism only.

The stimulus is delivered at the tendon by means of a pendulum, "e," which swings freely in a frame beneath the chair. This frame is firmly attached to the seat of the chair and is adjustable in a vertical direction. The pendulum begins the

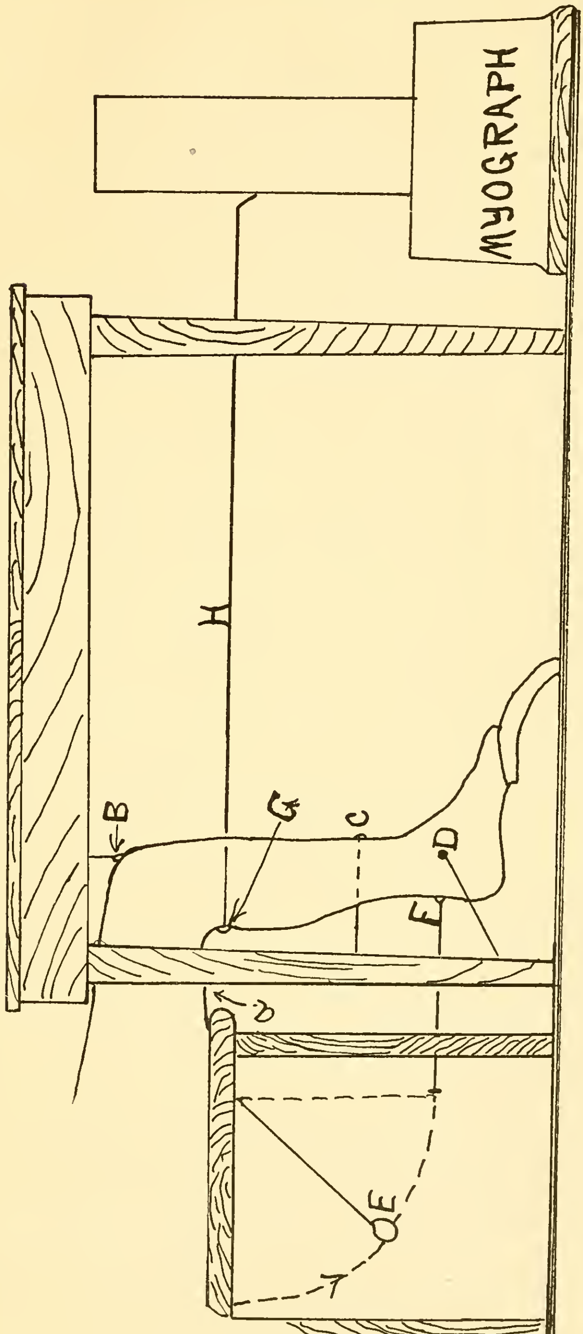

FIGURE I

swing at the horizontal level. A magnet attached to the chair holds the pendulum at this horizontal position. The electric current which controls the magnet is made and broken at the myograph. During the experiment the current is closed. A pointer reaches out at the base of the drum and, pressing momentarily on a bit of spring, breaks the current and releases the pendulum. The stimulus is transmitted from the pendulum to the tendon by means of a small bar of light wood about one inch square, "f." A slender strip of hard wood, attached to one end of this bar, meets the tendon; a rubber band holds it firmly but lightly on the tendon. This transmission bar is about 8 inches long and is adjustable as to length. The other end of the bar rests in or is supported by a double swinging joint, as it may be called. A small pin, cone shaped at each end, supports the frame holding the bar; the cone-shaped pin fits into a similar-shaped socket; a screw holds the pin in the socket firmly, but loosely enough to allow perfect freedom of movement. There are two of these joints; in combination, the joints allow free movement of the bar in a horizontal, backward and forward direction. A single joint tends to check this movement of the bar by pulling it up in a vertical direction. The combination of two joints eliminates this vertical pull and thus allows freedom of movement in response to the blow of the pendulum. The bar appears to respond to the blow as though it were resting in space. This transmission bar extends back such a distance that it meets the pendulum at exactly the vertical position of the swinging pendulum. Thus the pendulum "rests"—is held at the horizontal position —at the beginning of the quadrant, by the magnet. When the current is broken at the myograph, the pendulum falls through one quadrant, and striking the transmission bar when it reaches the vertical position—at the moment when the velocity of the single quadrant swing is maximal—, delivers the blow to the tendon.

The reflex response is taken directly from the Gastrocnemius muscle—not from the extension movement of the foot. A small piece of light wood is held gently on the external skin surface of the muscle, at or near the heads of the muscle, by means of a rubber band, "g." At this spot, which is a few inches below the knee, the reflex response of the muscle is maximal; the reflex requires a very limited number of muscle

fibers.[8] At the muscle this piece of wood is slightly hollow and is about 3 inches square; this large surface is for the muscle only. The piece of wood at each end is cut down to a small arm about one-half inch in width; this arm projects out at each side of the leg. When the muscle enlarges on contraction, the piece of wood moves in a backward and forward direction. A recording lever transmits this movement to the myograph drum, "h." Two limbs of this lever, one on each side of the leg, are attached to the projecting arms of the piece of wood which rests on the muscle. The connecting joint is a sort of universal joint; a rigid attachment at this point will not work. A strip of tin is tacked on each of the projecting arms and on each of the limbs of the lever. A notch is cut in each strip. The recording lever notch fits into the muscle attachment notch and is held securely but gently by a rubber band. Thus there is at least a minimum of restraint or resistance in the transmission of the total muscle movement to the recording lever.

These two limbs meet the "body" of the recording lever in front of the leg. The size of the "limbs" and "body" of this lever is as small as is consistent with lightness and firmness in all parts of the lever. No matter how light these mechanical transmission parts may be, there is doubtless some lag in transmission of the reflex response. On the other hand, if the lever is too small and too weak, it is apt to buckle a bit and thereby interfere with the transmission of the muscle response. Basswood was used in all these mechanical recording and transmission parts; this wood appears to supply a maximum in this combination of lightness and firmness.

The external end of the lever—the myograph end—is attached to an L-square piece of bakolite. The short limb of this square holds a vertical position and is attached directly to the long limb of the recording lever. The long limb of the square narrows down to a small point in which fits a celluloid marker;

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[8] According to BERITOFF, contraction of a muscle is greatest at or near the entrance of the nerve and diminishes or may become zero at or near the distal or tendon end. It may be noted here that the stretch stimulus causes the recording lever to move in the same direction as does the contraction of the muscle; in both cases the muscle enlarges. The fibers in this muscle are arranged diagonally; their attachments at the central end of the tendon make acute angles; the fibers meet the tendon obliquely. These angles are small—10° for example—at the distal end and larger at the proximal end of the muscle. On contraction these angles increase in size—as much as 3 times. The pull of the tendon or stretch of the muscle appears to produce a similar effect; it slightly increases the size of the angles which the fibers make with the tendon attachments. (See *Pflüger's Archiv.*, 205:475 and 209:763).

this long limb holds a horizontal position. At the junction of the long and short limbs of this L-square, the bakolite rests on, is supported by, and moves freely in a cone-shaped pin-and-socket joint. A small pin or cylindrical bar is driven into a hole in the bakolite square; the cone-shaped ends of the pin fit into sockets similar in shape; a screw holds the pin snugly in the socket at both ends. At the same time, movement in the socket is perfectly free; friction is reduced to a minimum. Thus the slight backward and forward movement from the muscle is transmitted from the muscle to the marker. The marker moves in a vertical direction and records the amount of the muscle enlargement on the revolving drum.

The myograph is a Starling-Sherrington model made by C. F. Palmer. It is driven by a Leeds and Northrup constant speed motor. A screw at the top of the vertical shaft on which the drum revolves enables one to raise and lower the drum any amount and at any time when the drum is moving. Gears and speed variation pulleys at the motor and at the myograph permit a wide range of speed. The time record is made by a marker of the tuning fork type; the time is recorded in 10 sigma increments. The time record is made at the beginning, before any reflex records are recorded, and after the individual experiment is complete. The speed of the drum is naturally the same in making the time record as in making the reflex records.

Is the external stretch stimulus constant? Two variations in the stimulating device might influence the constancy of the stimulus and, in consequence, might exercise some control over the latent time. (1) *The velocity of the blow at the tendon.* The essential factor in this stretch stimulus is the quickness and suddenness of the blow; that is, the velocity of the blow as the pendulum hits the tendon. For example, if the pendulum falls through one-half quadrant instead of one quadrant, the velocity is diminished and the time-course of the muscle responses is more or less disturbed. In all cases during the present experiment the pendulum fell from the horizontal to the vertical position; that is, from the beginning to the end of one quadrant. Hence there is no chance for any change in the velocity of the blow; it is uniformly the same for each individual. (2) *The weight of the pendulum.* With a constant velocity any change in the weight of the pendulum causes little if any change in the latency in any one individual subject. DODGE

tested this factor with the following results. With a constant velocity the weight of the pendulum was progressively increased. The figures are for the same subject.

TABLE 1

The Relation of the Weight of the Pendulum to the Length of the Latent Time: Velocity of Pendulum is Constant.

Weight of Pendulum	*Latent Time in Sigma*
25 grms.	31.5
50 grms.	33.
75 grms.	32.1
100 grms.	31.
125 grms.	30.7
150 grms.	31.7

(From Zeitschrift für allgemeine Physiologie, 12; 32.)

In the present experiments the weight of the pendulum was adjustable by two 20 grm. and one 30 grm. increments. The aim was to make sure that the response was maximal—as much contraction of the muscle as the mechanism in response to the stretch stimulus was capable of setting in action. A stimulus of greater velocity—more nearly instantaneous—would very likely diminish the latent time; but the velocity is constant. The addition of one 20 grm. and the 30 grm. weight was found to be ample for all the subjects. A minimum weight was ample for the most sensitive, most responsive subjects. In the case of these sensitive subjects, increasing the weight of the pendulum up to the regular level used with other subjects—as indicated above—did not appear to evoke any change in the latency. Usually the only variation in the response was a sort of rebound of the muscle at the end of the latent period. The blow appeared to be too heavy. As the lever described the small curve—the latency curve—it was jerked back beyond the base line. This made it difficult to measure the length of the latent period. Taking out the 30 grm. weight usually eliminated this. It appears reasonable to conclude, therefore, that the external stimulus in the present experiment is constant; it is not a factor in the individual variation in latency. In each individual the stimulus excited enough—very likely more than enough—muscle fibers to set off the muscle contraction.

Several critical features in the set-up demand attention. (1) The reflex readiness to respond. This is a tonic condition. When the foot hangs limply extended there is no response, no

matter what the stimulus may be; there is too much slack to be taken up. When the foot is placed in such a position that the tendon and muscle are in a condition of slight tension, two results follow: (a) There is a heightened condition of excitability in the muscle fibers. The flexible support beneath the foot raises the foot and thereby stretches the muscle; this support is a piece of tin and offers a minimum of resistance. The optimal position is midway between flexion and extension. In other words, the muscle is most or, at least, normally responsive when at or near its resting position in the body. The greatest change in responsiveness takes place with very small increments of increase in passive or resting stretch. The optimal condition of full responsiveness covers a rather wide range. (b) This initial passive stretch which is under the control of the experimenter slightly excites muscle end organs and in consequence sets up a slight flow of nerve impulses along the reflex arc. This puts the other elements in the reflex—other than the muscle—in a condition of readiness to respond.

It is believed that, so far as the external controls are concerned, the tonic condition of the muscle and the other elements in the reflex arc was constant for each individual. The initial stretch appeared to be optimal in each instance. There is no difficulty in making this adjustment for the muscle is very responsive over a wide range of change in the position of the foot. The reflex was set in action many times before any records were made. The reflex arc was thoroughly "warmed up."

(2) In the individual set-up the knee ought to be on a horizontal level with the thigh. If the thigh is below the level of the knee; that is, if the leg between the thigh and the knee tends to a vertical position, there is apt to be some circulatory disturbance. The subject is also more or less uncomfortable. Several cushions in the chair made the horizontal adjustment possible and in consequence increased the comfort of the subject. (3) The adjustment at the ankle frequently causes some discomfort and demands more or less attention. It is essential that the metal cups meet the enlargements at the ankle and no more; they must not press tightly, for the subject's comfort demands a minimum of pressure at these points. The apparatus at these points is adjustable in many different directions. Consequently it is possible to secure a maximum of comfortable adjustment for the subject and an accurate set-

up for recording the reflex. Each subject was specially urged to insist on a comfortable position at all points. The attachment at the patellar bone offers no difficulty; there is no pressure at this point. The apparatus merely meets the bone—no more—and thereby prevents any upward movement of the leg.

(4) While the reflex record is being made the subject is reading an interesting story from Irving's Sketch Book. These stories appeared to serve the purpose best. The purpose is to make sure that the subject is perfectly calm and at rest, with attention on something external to himself. In many instances he forgot about the experiment; this is the ideal condition. The reflex then is free to respond in what may be called a "normal" manner—as free as possible from disturbances external to the reflex arc itself. In many instances the subject did not read; he watched the procedure. His attention to the reflex appeared to make no difference in the response; the response was uniform throughout the records. Other men presented various difficulties. Some men were completely "inhibitory"; it was impossible to elicit any response at any time —not even with the reflex hammer. Some of the "inhibitions" were due to injuries at the ankle or in some other part of the foot or leg. DODGE found subjects who were completely inhibitory. Some subjects exhibited a more or less erratic response; at one time the response is good; on the next trial there is no response; the next trial may show a small response. Naturally such subjects cannot be used. The essential aim is to secure the records of about 40 successive reflex responses in each subject; these responses must be very uniform. It is assumed that 40 consecutive individual records of uniform size present a good picture of a given individual's "normal" reaction when the Achilles Tendon is tapped. In some cases the experimenter had to use exceptional means to secure this number of records. In one case, for example, reading the story had no effect; the subject's attention was on his reflex with consequent erratic reactions. It was found that when this man hummed a tune at certain intervals, the erratic reactions disappeared. The experimenter gave the word; at varying times after this signal the pendulum was released. In this way uniform responses were obtained. When the man did not hum the tune there was complete or partial "inhibition." Apparently his reflex mechanism was very sensitive to the "inhibitory" impulses generated in the frontal lobe. In other cases an attempt

was made to control attention by having the subject say "ah" as the tendon was tapped. This plan failed to give results.[9]

The subjects were college students. Some 20 were taken from the Summer Session students. One man, number 80, was taken from the Extension Department. One man, number 45, was a graduate student. The other subjects were Columbia College students. About 100 men were used; many of these were erratic, inhibitory, or presented some disturbance which made it impossible to secure the kind of records sought for. Eighty subjects presented satisfactory records; these records are the subject matter of this report. It is well to remember that these subjects are a highly selected group. The fact of admission to any college means selection. Students in Columbia are double-selected, as it were; the requirements for admission to Columbia College are more severe than in many other colleges. Hence it is a group of superior men whose reflex reactions are here examined. In all cases the subjects were thoroughly cooperative; they were students in the Department of Psychology and usually were taking their first course in Psychology.

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[9] It is doubtful if the erratic, inhibitory phenomena manifested in several of the subjects were due to volitional impulses. Some men, who did not exhibit the slightest trace of inhibitory behaviour, were told to block the reflex response—"don't let your foot move when I give the signal." In no case was the man able to block the reflex; the reflex took place regardless of the efforts to block it when the pendulum hit the tendon. Presumably such an attempt to block the reflex consists chiefly in a voluntary contraction of the flexor antagonist; such a volitional innervation must be intermittent—not a constant stimulus. WARNER and OLMSTEAD (BRAIN, 46:189) report an "inhibitory" center in the frontal lobes. Ablation of the frontal lobes immediately evokes extensor rigidity; the presence or absence of the motor area has no influence on the rigidity. Stimulation of this frontal lobe area abolishes the rigidity. Thus, using SHERRINGTON'S theory of the inhibitory function as a basis, one may say that stimulation of the frontal area (1) shuts off or prevents a discharge of impulses into the extensor muscle or (2) sets up a discharge of impulses into the flexor antagonist or (3) both. In either case the discharge of impulses from the frontal lobes is constant. These frontal lobe impulses travel through the Cortico-ponto-cerebellar tract; thence through the superior peduncle and Red nucleus.

CHAPTER IV

THE LATENT TIME IN THE REFLEX; WHAT IT CONSISTS OF; HOW IT IS MEASURED

The reflex is essentially the contraction of the Gastrocnemius muscle in response to a stimulus which originates in the muscle itself. The myograph record distinguishes these two factors; (1) the muscle contraction; when reflexly excited this contraction records a curve; this curve begins with the long downstroke of the recording lever. This stroke runs parallel with the quick downward movement or extension of the foot. Then follows a more or less flat plateau or crest; this plateau is shown only when the myograph is moving rapidly. This reflex contraction curve ends in a rather quick return to the base line. (2) The latent period of the reflex. During this period the mechanism which excites the contraction is in action; that is to say, the stimulus or tendency to excite at the distant point—at the muscle fibers—is travelling around the reflex arc. The entire reflex arc is essentially an excitatory mechanism, for conduction means the rapid excitation of successive increments of nerve fibers and synaptic junctions. The present experiment is concerned *only* with the excitatory mechanism. *How long* does it take this mechanism to get the stimulus to the muscle fibers and thereby elicit a contraction of the muscle? One must isolate this period during which the stimulus is thus travelling to the muscle and establish a line beyond which the latent time does not run.

This latent period in the reflex begins with the application of the stretch stimulus at the muscle end organs. It closes with the response of the muscle fibers. The record depicts only those changes which take place within the muscle. Before the record begins, the pendulum has delivered the blow on the tendon. This blow has initiated the sudden change in the tension or stretch which is the normal or adequate stimulus. This sudden change in tension has been transmitted to the muscle. The initial downward movement or deflexion of the myograph lever records the moment when the stretch stimulus reaches the muscle end organs; at this moment the latent time begins. This initial deflexion exhibits three phases of the stretch: (1) The downward deflexion which is the stretch movement or period of sharply increasing tension; this

period covers about 15 sigma. (2) The period of maintained tension; in no case does the lever make a sharp return; in no case is the stretch stimulus instantaneous. The new, suddenly increased tension continues for an appreciable time. (3) The period of declining tension; the tension, for example, in the tendon, returns to the initial level; the myograph lever returns to the base line.

The effective or adequate stimulation takes place chiefly during the sudden change in tension—the stretch movement. It was just stressed that the stretch stimulus is never instantaneous; in fact, it is rather a continuous stimulus or state of tension. The muscle end organs are specially adapted to this kind of stimulus. An electrical stimulus does not reexcite the nerve, for the nerve immediately becomes adapted to the stimulus. This process of adaptation is much slower in the muscle end organs; a constant stimulus continues to excite these organs.[10] This means that the state of excitation set up in the end organs outlasts the stimulus. The single tap on the tendon is able to send out a considerable number of impulse volleys or series of impulses into each nerve fiber.

It should be noted that the time occupied by the sudden change in tension is independent of the latent time in the reflex. In the quickest possible stretch—presumably about one sigma—this time is about one-quarter of the latent time. In the present series this stretch movement time is about one-third of the latent time. Stimuli which are more closely instantaneous—which deliver the blow at the tendon with increasingly greater velocity—excite a relatively greater number of end organs and excite the greater number more or less simultaneously. But the muscle end organs have their own latency which depends on their own inherent excitability. Doubtless the tap on the tendon—a relatively slow stretch—excites many times more end organs than are actually essential; the work which the muscle does in the reflex is very slight. When one remembers that this stretch stimulus is briefly continuous and continues to excite; that the stimulus is also recurrent in the sense that the tension movement in the taut tendon is repeated—the tendon does not immediately

[10] For example; at the end of one second the discharge of impulses from the end organs was at the rate of 145 per second; at the end of 10 seconds this rate was 104 per second. The constant stretch stimulus continues to excite (Adrian).

return to an equilibrium; when one keeps these facts in mind, one is pretty sure that there is an ample discharge of impulses into the nerve fibers. In fact this discharge continues till the muscle responds. This is well illustrated in some of the records where there are two or at least one and a fraction of another deflexion during the latent period. The single oscillation or wave of suddenly increasing tension is not enough to set off the contraction of the muscle. The muscle contraction appears to break into the discharging impulses at the moment when these discharging impulses are ample both in frequency and in the size of the volley—number of nerve fibers set in action—to start the contractile response.

The latent time consists of a chain of interrelated events. In the first place there is the stimulation and response of the muscle receptors. The impulses generated in these organs stimulate afferent nerve fibers. The impulses set in action in these nerve fibers transmit the stimulus. It is to be expected that the conduction and transmission of this stimulus takes considerable time—relatively speaking—for the arc is by no means a short one. There is, in the second place, the conduction from the muscle to the dorsal horn synapse; thence through the spinal cord—lateral columns—to the prespinal center or centers. In animals this center appears to be Deiter's nucleus; in man other centers may be in the mid brain. In these prespinal centers the afferent impulses are transformed into efferent impulses. Then follows conduction along the efferent limb of the arc; in animals this efferent path appears to be the Vestibulo-spinal tract; in man, there may be some other efferent pathway which conducts the stimulus to the ventral horn synapse; thence to the termination of the motor nerve fibers at the muscle. Another event is the passage of the stimulus from the nerve fibers into the muscle fibers. There appears to be an intermediary something at this spot, between the nerve fibers and the muscle fibers. Perhaps it is best to follow SAMOJLOFF'S recent conclusion that this something is a chemical process or mechanism. The impulses in the nerve fibers set in action some chemical process and thus elicit some stimulus substance; the muscle fibers are specially adapted to respond to this stimulus thus produced. At any rate the stimulus which has been transmitted from the tap on the tendon passes over this "chemical bridge." The muscle fibers respond to this stimulus (1) after a brief period

of latency during which an ionic interchange takes place—the preparation for the contraction; at any rate this is the assumption. (2) After a brief period of rigidity. For an appreciable length of time after the ionic response the muscle is rigid and markedly resistant to any change of form. The time or length of this period appears to differ in different individuals; it is certainly part of the total latent time of the reflex. Very likely the underlying mechanism in this rigidity is the viscous-elastic acceleration which appears to be one of the preliminary components in every muscle contraction (Gasser and Hill). This initial rigidity may be a factor in determining the shape of the latent time curve in the second type of curves; the single impulse volley starts a response in the muscle but a very small one. When reinforcements arrive in the shape of other volleys of impulses, the muscle response is complete. The first volley elicits a small response because of the muscle resistance. The latent time is thus the sum of these different items in this closely interrelated chain of events. These events take place more or less simultaneously in each nerve and muscle fiber. The muscle responds as a unit.

The latent time in a given individual is measured as follows: The myograph record is set under a small magnifying glass—9-power. A small sharp-pointed caliper "gets" the length of the latent period in the given reaction. This length which the caliper records is measured at the time scale on the myograph record which the tuning fork has already recorded twice; this time scale is in 10-sigma intervals. There is no doubt that the essential problem in this measurement is to fix the beginning and the end of the latent period. The latent time is indicated by the small wave or curve in the record. The beginning of this curve indicates the time when the stretch stimulus reaches the muscle. This beginning of the latency presents no difficulties. When does the latent period end? There are several types of latency curves. In the first place there is the single wave curve. This is illustrated in Figure 2. In this type or record the recording lever responds with a small wave or curve and returns to the base line. The reflex response may begin immediately on this return of the lever to the base line; this immediate response always takes place when the latent time is brief. In Figure 2 the latent time is relatively long—the record belongs to subject number

34; the lever returns to the base line and stays there briefly before the muscle contraction begins. The muscle contraction is exhibited in the long downward swing of the lever.

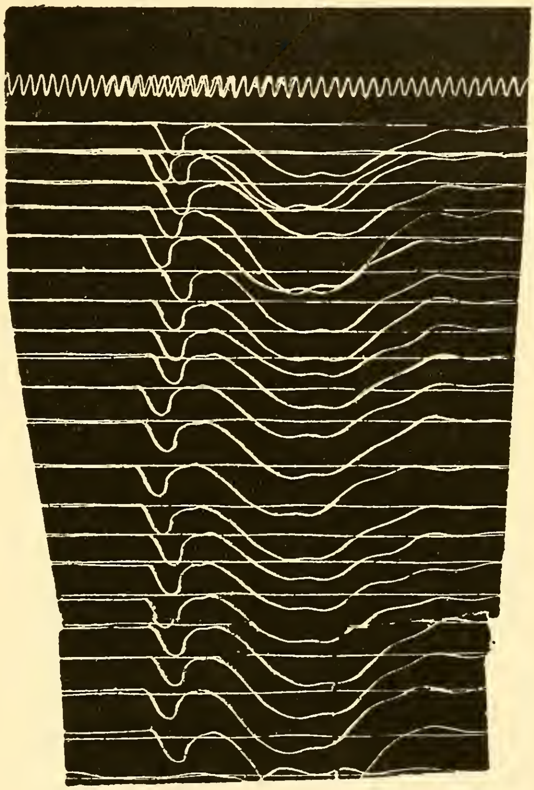


FIGURE 2

Usually the latent time in the slow individual is broken up into two full curves. The lever records one curve and returns to the base line. Immediately a second curve is recorded, the lever returning again to the base line; at this moment the muscle response begins. Then there is the type of latency curve which consists in one wave and part of another. The recording lever responds with a small curve; returns to the base line and starts on another wave. Just as the second wave reaches the end of the downstroke the response of the muscle breaks in; the length of the downstroke is the same in each wave—the whole wave and the part wave. In some cases there is a tendency for the second upstroke to begin—the upstroke of the second wave.

CHAPTER V

The Mental Tests; Their Administration; What They Measure; Are the Reactions in the Tests Comparable to the Reactions Which Take Place during the Latent Period in the Reflex?

The mental tests employed are as follows:

The first addition test in the Courtis series.
A letter cross out test.
A figure cross out test.
A completion test.
An easy word-object association test.
An easy word-opposite association test.
The Taylor recognition test.

With one exception these tests are in common use; the particular reaction in each test is relatively elementary. They are "speed" tests and not "power" tests. The Taylor test is not so well known; hence some account of what takes place in this test is in order. The numbers 1 to 50 are well mixed up and printed on a sheet of paper. No two consecutive numbers are together; usually consecutive numbers are widely separated. The test consists in taking a pencil and connecting the numbers in consecutive order. That is, for example, the subject draws a line from 1 to 2; then to 3; then to 4 and so on up to 50. The score is the total time taken to make these consecutive connections. It is likely that there is a semblance of "power" in this test as opposed to "speed." This matter will be taken up later.

These tests were given immediately after recording the reflex reactions in each individual. The experimenter explained just what was wanted as each test was presented to the subject. He then told the subject (1) to get ready for the test—pencil in hand; suitable position and suitable grip on the paper and pencil. (2) To begin at once at the signal "go." (3) That the time taken in doing the test would be measured by a stop watch. Nothing further was said after the signal was given except in some cases to set the subject going in the right direction. To some extent the experimenter watched the individual reactions; he was careful to stand behind the subject so as not to interfere with the subject's performance. There

was no other person in the room while the tests were being given.

THE TESTS EXHIBIT SPEED OF REACTION as their chief characteristic. At any rate this was the objective in selecting them. Speed of reaction is something tangible; it can be measured in terms of a definite unit—the time unit. But one must remember that these tests consist of acquired reactions. In all learning the speed of performance at the beginning is far different from the speed of performance at the end of learning. At the beginning, any learned reaction such as $4 + 3 + 6$ operates slowly. Such a reaction is functional in nature; like any other function it is the synthesis of various other active elements. At the beginning one discriminates, compares, recalls, recognizes and does a lot of other things. In particular, one is sharply conscious of these independent but cooperating reactions. One might call them the building material; with this building material the individual constructs the new function—adding 4, 3, 6. As the learning proceeds these structural elements tend to fuse into a new unit-reaction. Then one becomes conscious of the new unit-reaction and it alone—ought to at any rate. With a single stroke of attention one perceives the problem; this unit perception leads straight and immediately to the end result—the sum. Naturally the more perfect the learning, the more perfect the fusion of the structural elements and the more speedy the reaction; then one is dealing with a function in a relatively perfect state of responsiveness. In this ideal condition there is no counting; one does not have to see 4 balls, for example, and 3 balls and 6 balls and then count up the total. Nor does one have to examine the outline of this figure to make sure it is a "4." In many of these 80 subjects this ideal does come to light, such as subjects 1, 2, 18, 45. On the other hand, many subjects depart more or less widely from this ideal; their learning is relatively incomplete.

Nevertheless in these tests *Speed of performance is the single variable;* the time score measures speed of performance only. In complete learning any other variable tends to approach zero in value. Some of the men in this group—just mentioned—exhibit relatively complete learning. A score of 69 or 77 on the addition test is pretty close to the very top notch; in such a performance there is practically no variable except the sheer time of reaction. In all the tests this single

variable is measured and only this variable. It is doubtless true that other variables continue active; the learning is often far from complete. Furthermore, the mental function or network of functions known as "intelligence" is in some degree a factor in varying the response of different individuals on the same test. Foresight is certainly a factor in intelligence; it is a second variable for some of these 80 subjects in at least one of the tests—the Taylor Recognition Test. This second variable disturbs the results; it is not a question of having or not having a particular ability; rather is it a question of using or not using what one does have in potential form.

Furthermore, in these tests, speed is usually, if not always, exhibited in operating different functions, one after the other. This means setting up action in one function; stopping action; passing on to another function and repeating the performance again and again. This sort of reaction is more or less intricate. It is pretty apt to involve something which is not speed at all. The subject may, for example, stop all action for a moment; some defect in his learning prevents his advance. This temporary block is not a constant factor for all the subjects. This or that man exhibits this block because he does not know all the combinations in addition. Other variables such as those just mentioned must be reckoned with in interpreting the individual performance; this problem will be taken up later. For the present, attention is directed to the single variable—speed of performance. It is assumed that, in adding 4, 3, 6, the subject has been over the route so many times and knows the "road" so perfectly that the only item to be examined is the time it takes him to make the "trip"—to perform the function.

The measurement of this single variable is not an end in itself. The essential objective is the comparison of these speed measurements on the tests with the speed of reaction measured in the reflex latent time. Is it proper to make this comparison on the basis of the single variable—the speed of reaction? Speed of reaction may be the variable in two given types of reaction and yet the comparison between these types of reaction may be futile. Unlike structural and functional conditions may be far too numerous. This is notably true in the present inquiry where the essential problem is the possibility that one type of reaction, the latent time in the reflex, is a criterion of potential speed in the other type of reaction, the

learned reactions in the tests. Hence one must know very precisely what is being compared. Are the things compared really comparable? What comparable elements are common to both types of reaction? What elements are present in one but not in the other type of reaction?

Suppose one examines the two types of reaction which are to be compared in this inquiry. Take the reflex latent time. It is an unlearned reaction. The transmission and conduction of the stimulus, or tendency to excite, around the reflex arc exhibits what may be called pure "speed." This speed of reaction in the latent time is exhibited in starting action at excitatory mechanisms; conducting nerve impulses in nerve fibers and transmitting these impulses at synaptic junctions. There are about 2½ meters of nerve fibers, afferent and efferent; 2 spinal synaptic junctions and at least one large prespinal center or synaptic junction in the brain stem (these prespinal centers may be in the mid brain); the neuromyal junctions or transmission mechanisms between nerve fibers and muscle fibers. Speed or quickness in these elements centers chiefly in the movement of nerve impulses; these impulses are essentially conducted and transmitted tendencies to excite at some distant point. The impulses carry the stimulus. There is a continuous forward movement of the stimulus along the reflex arc. This movement is slowed up at the synaptic junctions and at the neuromyal junctions; but this slowing up is present in every individual, differing, it is true, from one individual to another and due to the intrinsic speed conditions at these points. So far as one can see, there is nothing in the reflex latent time which cannot be classified as speed—the rapid or slow movement of the stimulus from one point to another point. Furthermore, this reflex mechanism is set in action hundreds of times every day during the life of the individual. It subserves the endless changes in posture dependent on the slight but changing amounts of contraction in the Gastrocnemius muscle. In this postural activity of this reflex there may be some relay action from one set of nerve fibers to another. Aside from this there are no alternative paths; no semi-independent but closely allied functions which may be in action today but inactive for long periods of time. The reflex is a unit mechanism; essentially the same mechanism, the same neural path, is in action each and every time. Consequently the reflex mechanism is or ought to be in per-

fect "running condition" so far as constant use can make it.

On the other hand, consider the different learned reactions in the different tests. These learned reactions include structural and functional elements similar to those in the reflex latent time. There are about $1\frac{3}{4}$ meters of nerve fibers, afferent fibers from the retina to the visual area and efferent fibers from the cerebral motor area to the arm, hand and fingers. There is the anterior horn synaptic junction and various neuromyal junctions. If one follows SHERRINGTON (PRS., 97B: 519) and considers the synaptic junction as essentially an excitatory mechanism, then the excitatory mechanism at the motor area comes within the limits of similar elements—to some extent at least. In these learned reactions, as well as in the reflex, speed is exhibited in setting up action, conduction in nerve fibers and transmission at synaptic junctions. In both types of reaction, the fundamental basis of speed is the velocity of nerve impulses; at least this is true for the motor side of the learned reactions. Furthermore, these similar elements are constantly active—with this difference. The reflex elements are active in the performance of one and the same function—the postural control of the Gastrocnemius muscle. These similar elements in the learned reactions are active in the performance of different functions. Each and every one of these functions is a unit, more or less independent of other functions. For example, adding 4, 8, 5 is not the same as adding 2, 9, 6 and still less similar to crossing out 2's. It is expected that these elements, taken as a whole and regardless of the individual functions which are being performed at any one time, exhibit speed variations in different individuals. This must be true since individual differences in speed of performance on these same tests is an experimental fact.

But these learned reactions include something which is not present in the reflex latent time reaction. There is the region between the terminus of the optic nerve fibers in the visual area and the reaction set up in the motor area. That part of any total reaction which takes place in this region is strictly mental or psychic in nature. Here are to be found such pure mental factors as volition, incentive, foresight. The greater part of learning is governed by these and other strictly mental factors. It is a fundamental part of this experiment that mental factors shall be present in one type of reaction. Com-

parison is made between speed in reactions which have nothing particularly mental about them and speed in reactions which do contain strictly mental elements. These mental factors are present in all reactions in the given tests; every individual exhibits them and makes use of them. Consequently the mere presence of these mental factors does not disturb the validity of the experimental results.

None the less, considerable disturbance does appear when one considers the *Individual variations within the mental part of the total reaction.* A mental factor, such as volition may be called "flexible" in the sense that the exercise of volition brings out a graded adjustment in terms of more or less speed. At the same time, any such mental factor or function tends to become hardened into habit and thereby loses much of its flexibility. The individual may settle into some definite speed level and stay there, no matter what the situation may be (DOWNEY gives some illustrations, page 98). This habit or these habits are acquired reactions; they may or may not be the same in any two individuals. Take some illustrations: a stimulus which excites to action—acts as a stimulus or incentive—in one individual, may block or inhibit action in another individual. This or that individual may fail to use all his resources; he never looks ahead; never foresees the situation to come; never prepares the way for the full use of some automatic speed mechanism. The individual can do this, but he habitually does not, while another individual habitually does look ahead. Both individuals may have the same potential ability to do this; the one is using it; the other is not. In the reflex latent time, the stimulus or conducted tendency to excite at some distant point is always moving toward that point; there are no in-between stops in some one or more individuals. On the other hand, at some part of the learned reaction, such as adding 4, 8, 7, there comes a temporary stop; something blocks. This total stop operates as a variable in THIS individual. In another individual there is no such total block, but the reaction at some point and for some reason is slowed up. In still another individual or individuals, there is neither slowing up nor block. The man perceives with a single stroke of attention 4 + 8 + 7 and immediately writes 19. The fact that this or that variable is present in one individual but not in another individual is a serious matter when one attempts to compare speed in the two types of reaction. These individ-

ual variations must be reckoned with in the interpretation of results; they are so many uncontrolled variables. The sole variable ought to be the intrinsic conditioning factors whose speed of performance the time measurement is presumed to bring to light. It will presently be shown that the above and other individual variations have been acquired; they are defects in the individual learning. They operate to prevent the full manifestation of the individual speed of performance.

CHAPTER VI

The Scores on the Tests and Latent Time. Graphic Representation of the Measures. Central Tendencies. Measures of Dispersion

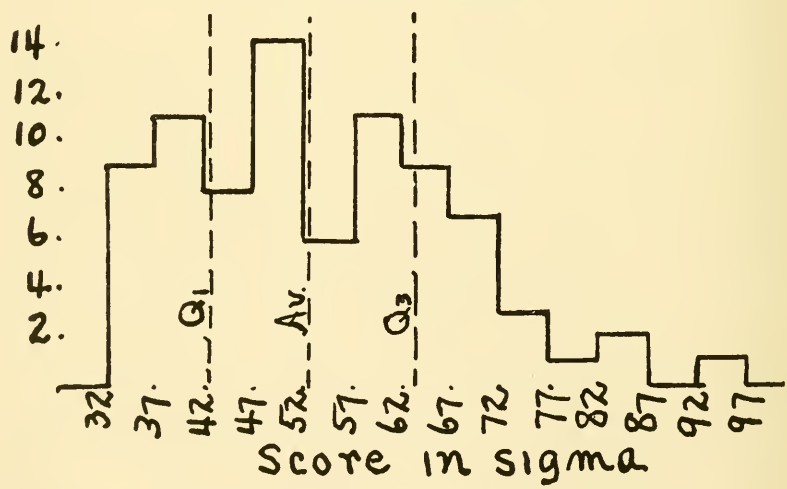
The raw scores on the different tests are given in Table 2. The small figures directly beneath the given score indicates the quartile to which this score belongs. For example, in the case of number 45, all scores belong to the first quartile. The first quartile includes the smallest scores; the men who make these small scores are the most speedy. The fourth quartile includes the largest scores; the men who make these large scores are relatively slow. Two rank orders are given: (1) The rank order of the 80 men according to the length of the individual latent time. For example, subject number 1 exhibits the shortest latent time; subject number 80 exhibits the longest latent time. (2) The rank order according to the size of the individual's total score. For example, the smallest total score is 510; this score belongs to the man whose latent time rank order is 45. When ranked according to the size of his total score this man's rank order is number 1.

The frequency distributions and various relative data are given in the following figures. For the most part the different distributions take the "moderately asymmetrical form." The greater frequencies lie toward the lower end of the range. YULE calls this the most common of all smooth forms of frequency distributions. One might expect this type of distribution since the group consists chiefly of extra selected, superior men; the slow men are relatively few and scattered over a relatively long range. Under each figure are given relative data concerning the distribution such as the average, median, standard deviation, skewness, probable error. The relation of Q to S. D. is also given. According to YULE, Q, the semi-interquartile range, is usually about ⅔ of the standard deviation in distributions of the moderately asymmetrical type; a range of 10 points in this ratio does not indicate much displacement of this relationship.

In the normal curve the mode, median and the average coincide. Actually a given distribution is usually pulled away from this symmetrical type. In the present measures the distributions are usually distorted in the direction of the larger scores.

The range in each quartile gives some clue to the spread or scatter at different parts of the distribution. In terms of seconds the range in the third quartile is the same as that in the second quartile; this is true for the combined association tests and the latent time. In all other measures the range of the third quartile is slightly less than that of the second quartile. That is to say, the third quartile measures cluster more closely about the average—except in the latent time and association tests. The range of distribution in the first quartile is always large, sometimes twice as large as the range in either the second or third quartile. The range of distribution in the fourth quartile is always much larger—2 or 3 times larger—than the range in the first quartile. Consequently the measures on the large score end are considerably more spread out than the measures on the small score end of the distributions. In the latent time distribution the group is massed toward the small latent time values. The first three quartiles with a total range of 31 sigma include 80% of the cases. The fourth quartile

FIGURE 3
THE LATENT TIME DISTRIBUTION



S.D.	$2.67 \times 5 = 13.35$
Average	53.2 P.E.$_{av}$ 1.006
Median	52.
Q_1	43.25
Q_3	63.68
Q	10.22
A.D.	11.12
P.E.$_{dis}$	9.004
Skewness	+.27

QUARTILE RANGE

I	II	III	IV
11	10	10	33

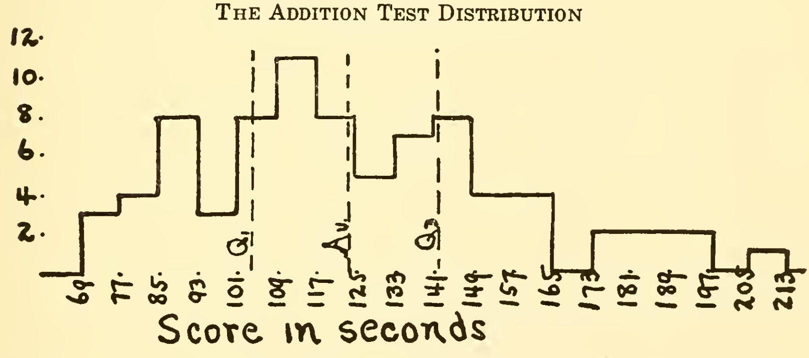
$$\frac{Q}{S.D.} = .76$$

y–measures are the frequencies.

with a range of 33 sigma contains the remaining 20% of the measures. 40 sigma include 93% of the cases; only 6 cases lie beyond the 72 sigma limit. It is noteworthy that in the latent time distribution, quartiles 1, 2, 3 are practically the same in range.

Since the tests were given individually, once to each man, no measure of reliability was secured. The time taken to secure the different measures was relatively long—about one hour. In some cases it was possible to persuade the subject to return a second time. Usually this was very difficult to bring about and frequently impossible since the men had plenty of other work on their hands. Consequently the attempt was given up.

FIGURE 4
THE ADDITION TEST DISTRIBUTION



S.D.	$3.84 \times 8 = 30.72$	
Average	124.2	P.E.$_{av}$ 2.3
Median	118.	
Q_1	103.	
Q_3	142.	
Q	19.5	
A.D.	24.4	
P.E.$_{dis}$	20.72	
Skewness	+.6	

QUARTILE RANGE

I	II	III	IV
34	21	18	63

$$\frac{Q}{S.D.} = .63$$

y–measures are the frequencies.

TABLE 2

THE RAW SCORES ON THE DIFFERENT TESTS AND LATENT TIME OF REFLEX

Total Score Rank	*Latent Time Rank*	*Latent Time*	*A.D.*	*Addition*	*Letter Cross Out*	*Figure Cross Out*	*Completion*	*Taylor*	*Word Opposite*	*Word Object*	*Total Test Score*
9	1	32	1.2	78 1	86 2	150 2	84 1	204 2	26 3	30 3	658
23	2	34	1	75 1	77 1	124 1	147 4	220 3	28 4	33 3	704
15	3	34	1.4	88 1	93 3	169 3	105 2	165 1	22 2	36 4	678
12	4	35	1.6	109 2	78 1	140 1	111 2	182 2	18 1	35 3	673
37	5	36	1	129 3	75 1	139 1	106 2	250 4	19 1	42 4	760
27	6	36	1.5	82 1	102 3	150 2	100 1	221 3	26 3	29 2	710
47	7	36	1.7	122 2	84 2	155 2	120 3	230 3	27 4	40 4	778
3	8	38	2	106 2	75 1	114 1	110 2	166 1	22 2	25 1	612
5	9	38	1.4	69 1	79 1	123 1	100 1	215 2	16 1	33 3	635
58	10	38	0.8	116 2	103 4	175 3	121 3	236 3	28 4	36 4	815
2	11	38	1.5	111 2	77 1	132 1	92 1	137 1	19 1	25 1	593
42	12	38	1.7	118 2	80 2	185 3	127 3	210 2	19 1	30 3	769
11	13	40	2.1	90 1	90 2	195 4	92 1	165 1	16 1	20 1	668
59	14	40	1.3	146 4	110 4	196 4	127 3	198 2	22 2	27 2	816
33	15	40	1.8	101 1	90 2	185 3	92 1	210 2	22 2	37 4	737
44	16	40	1	145 4	80 2	140 1	106 2	246 4	20 2	37 4	774
13	17	41	1.5	90 1	85 2	150 2	125 3	180 1	19 1	25 1	674
14	18	41	1.7	107 2	74 1	125 1	96 1	226 3	21 2	28 2	676
61	19	42	2	127 3	96 3	163 2	97 1	290 4	21 2	27 2	821
16	20	42	1.3	73 1	82 2	165 2	95 1	225 3	19 1	20 1	679
21	21	42	1.5	92 1	77 1	123 1	127 3	227 3	23 2	24 1	693
10	22	42	1.4	92 1	72 1	154 2	80 1	218 3	28 4	23 1	667
4	23	44	2.3	102 1	77 1	127 1	102 1	174 1	14 1	24 1	620
34	24	44	1.8	114 2	67 1	152 2	125 3	234 3	24 3	21 1	737
36	25	45	2.1	191 4	84 2	126 1	115 2	191 2	23 2	25 1	755
64	26	46	1.5	100 1	100 3	195 4	139 4	255 4	24 3	27 2	840
57	27	47	1.8	106 2	80 2	171 3	140 4	264 4	18 1	35 3	814

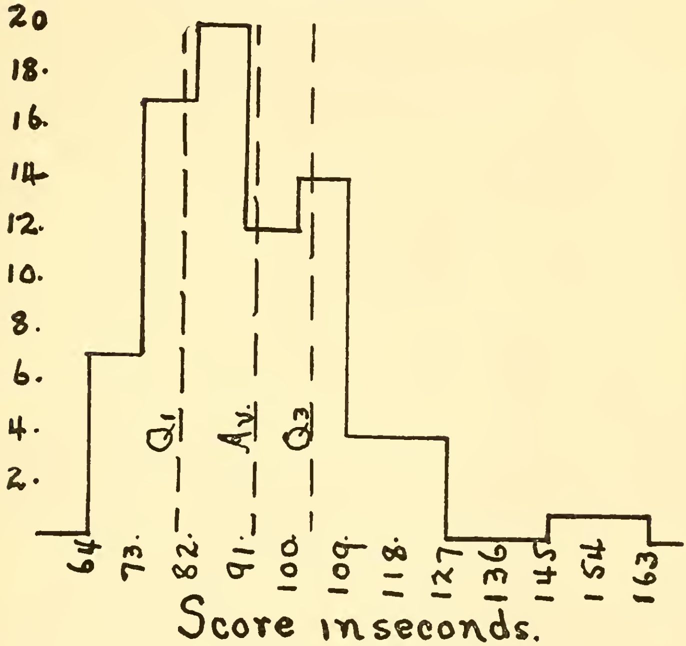
TABLE 2—CONTINUED

Total Score Rank	*Latent Time Rank*	*Latent Time*	*A.D.*	*Addi-tion*	*Letter Cross Out*	*Figure Cross Out*	*Com-ple-tion*	*Taylor*	*Word Oppo-site*	*Word Object*	*Total Test Score*
75	28	47	2.4	161 4	84 2	180 3	137 4	275 4	30 4	35 3	902
31	29	47	1.7	90 1	78 1	139 1	134 3	230 3	20 2	30 3	721
17	30	48	1.2	114 2	100 3	143 2	117 2	170 1	17 1	18 1	679
24	31	48	1.4	141 3	88 2	140 1	120 3	161 1	24 3	30 3	704
53	32	48	1.2	177 4	87 2	135 1	113 2	234 3	24 3	26 2	796
41	33	49	1.6	140 3	89 2	182 3	104 2	201 2	24 3	28 2	768
30	34	50	1.5	102 1	99 3	160 2	140 4	156 1	27 4	34 3	718
40	35	50	1.2	154 4	75 1	140 1	120 3	225 3	22 2	29 2	765
45	36	50	1.8	154 4	90 2	150 2	142 4	199 2	15 1	26 2	776
49	37	50	1.5	113 2	99 3	170 3	145 4	220 3	18 1	26 2	791
19	38	51	2	105 2	85 2	130 1	100 1	210 2	23 2	29 2	682
20	39	51	1.5	120 2	96 3	140 1	128 3	165 1	18 1	24 1	691
18	40	51	1.6	99 1	87 2	172 3	100 1	182 2	17 1	23 1	680
74	41	52	1.5	185 4	98 3	197 4	131 3	235 3	26 3	25 1	897
35	42	53	1.2	146 4	107 4	151 2	115 2	171 1	20 2	31 3	741
38	43	53	1.5	82 1	105 4	165 2	106 2	257 4	19 1	26 2	760
32	44	53	1.5	147 4	74 1	200 4	103 1	154 1	27 4	27 2	732
1	45	53	1.6	77 1	65 1	106 1	82 1	140 1	15 1	25 1	510
51	46	55	2.5	160 4	84 2	150 2	120 3	220 3	20 2	40 4	794
22	47	57	1.8	104 2	112 4	159 2	114 2	150 1	29 4	25 1	693
29	48	59	1.5	135 3	90 2	148 2	102 1	191 2	22 2	28 2	716
60	49	60	1.8	122 2	85 2	176 3	135 4	250 4	18 1	33 3	819
25	50	60	1.3	115 2	67 1	140 1	115 2	208 2	29 4	31 3	705
48	51	60	2.1	124 2	85 2	205 4	115 2	220 3	20 2	21 1	790
8	52	60	1.3	110 2	72 1	142 2	112 2	174 1	22 2	24 1	656
6	53	60	1.6	130 3	69 1	129 1	94 1	169 1	24 3	27 2	642
63	54	60	2.5	144 4	105 4	190 4	129 3	198 2	26 3	43 4	835
73	55	60	1.5	127 3	120 4	240 4	120 3	228 3	20 2	40 4	895

TABLE 2—CONTINUED

Total Score Rank	*Latent Time Rank*	*Latent Time*	*A.D.*	*Addition*	*Letter Cross Out*	*Figure Cross Out*	*Completion*	*Taylor*	*Word Opposite*	*Word Object*	*Total Test Score*
28	56	61	1.7	111 2	89 2	139 1	105 2	237 3	16 1	17 1	714
52	57	61	2.2	182 4	67 1	142 2	125 3	230 3	20 2	29 3	795
24	58	62	1.5	86 1	91 2	159 2	132 3	180 1	30 4	30 3	707
67	59	62	1.8	118 2	102 3	190 4	141 4	271 4	24 3	23 1	869
66	60	63	1.5	135 3	120 4	187 3	145 4	215 2	26 3	31 3	859
70	61	63	2.3	119 2	105 4	213 4	121 3	285 4	18 1	24 1	885
50	62	63	1.5	138 3	100 3	181 3	104 2	210 2	25 3	36 4	794
55	63	63	1.8	174 4	106 4	182 3	98 1	166 1	31 4	43 4	800
43	64	64	1.3	140 3	85 2	168 3	115 2	211 2	20 2	31 3	770
78	65	65	2.2	164 4	96 3	200 4	137 4	300 4	22 2	40 4	959
79	66	66	1.5	150 4	159 4	208 4	129 3	251 4	30 4	36 4	963
72	67	69	2	195 4	77 1	157 2	154 4	240 3	37 4	35 3	895
56	68	70	2.4	116 2	94 3	158 2	108 2	276 4	17 1	37 4	805
62	69	70	1.7	127 3	95 3	200 4	124 3	231 3	18 1	32 3	827
46	70	70	1.8	100 1	97 3	192 4	120 3	197 2	26 3	44 4	776
54	71	70	2.2	90 1	119 4	224 4	118 2	195 2	25 3	27 2	798
71	72	70	2.5	140 3	100 3	192 4	129 3	274 4	26 3	27 2	888
65	73	71	1.8	142 3	104 4	167 3	118 2	264 4	28 4	32 3	855
7	74	72	2	119 2	80 2	135 1	97 1	174 1	24 3	25 1	654
39	75	74	1.7	114 2	91 2	153 2	112 2	238 3	20 2	33 3	761
77	76	76	1.5	144 4	116 4	261 4	145 4	226 3	20 2	26 2	938
76	77	80	1.5	160 4	126 4	193 4	142 4	265 4	23 3	25 1	934
69	78	85	1.6	133 3	110 4	181 3	141 4	270 4	19 1	23 1	877
68	79	85	1.5	154 4	107 4	169 3	145 4	211 2	34 4	50 4	870
80	90	96	1.8	205 4	145 4	283 4	175 4	290 4	35 4	45 4	1168

FIGURE 5
LETTER CROSS OUT DISTRIBUTION



S.D.	1.91 × 9 = 17.19	
Average	92.35	P.E.$_{av}$ 1.3
Median	89.	
Q_1	79.88	
Q_3	102.57	
Q	11.35	
A.D.	13.72	
P.E.$_{dis}$	11.59	
Skewness	+.55	

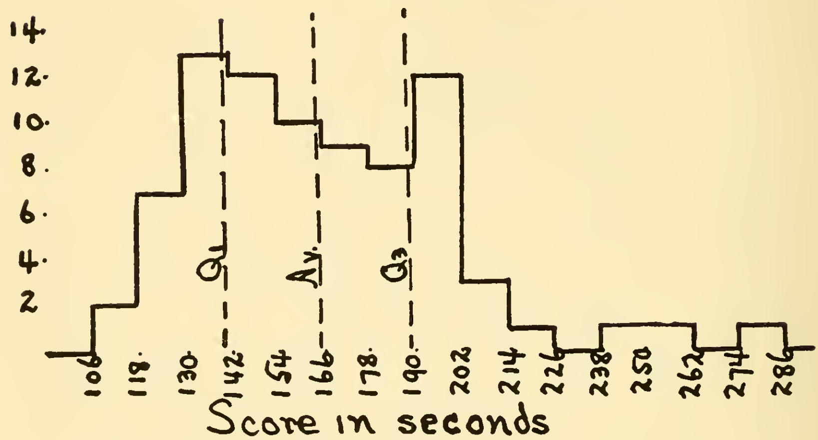
QUARTILE RANGE

I	II	III	IV
15	12	10	43

$$\frac{Q}{S.D.} = .66$$

y–measures are the frequencies.

FIGURE 6
FIGURE CROSS OUT DISTRIBUTION



S.D.	$2.7 \times 12 = 32.4$	
Average	165.4	$P.E._{av}$ 2.45
Median	161.	
Q_1	140.15	
Q_3	188.5	
Q	24.17	
A.D.	25.5	
$P.E._{dis}$	21.85	
Skewness	+.38	

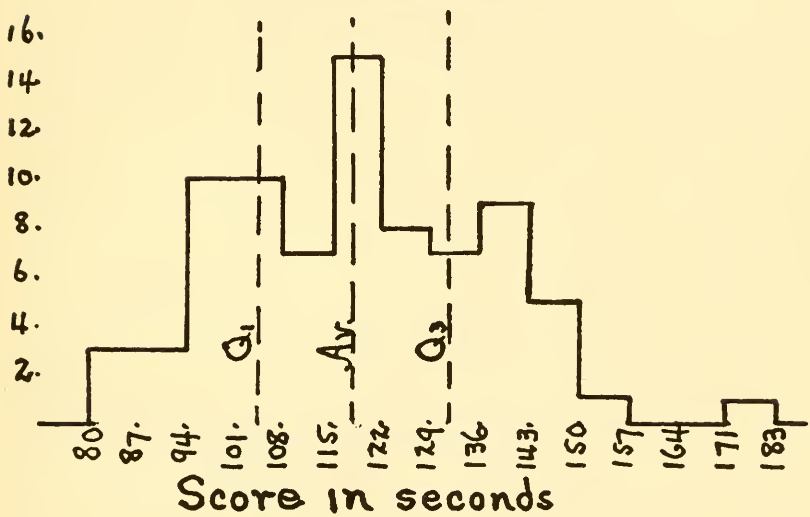
QUARTILE RANGE

I	II	III	IV
34	25	23	95

$$\frac{Q}{S.D.} = .74$$

y–measures are the frequencies.

FIGURE 7
COMPLETION TEST DISTRIBUTIONS



S.D.	$2.63 \times 7 = 18.41$	
Average	118.3	P.E.$_{av}$ 1.38
Median	118.	
Q_1	103.8	
Q_3	132.	
Q	14.1	
A.D.	14.52	
P.E.$_{dis}$	12.42	
Skewness	+.048	

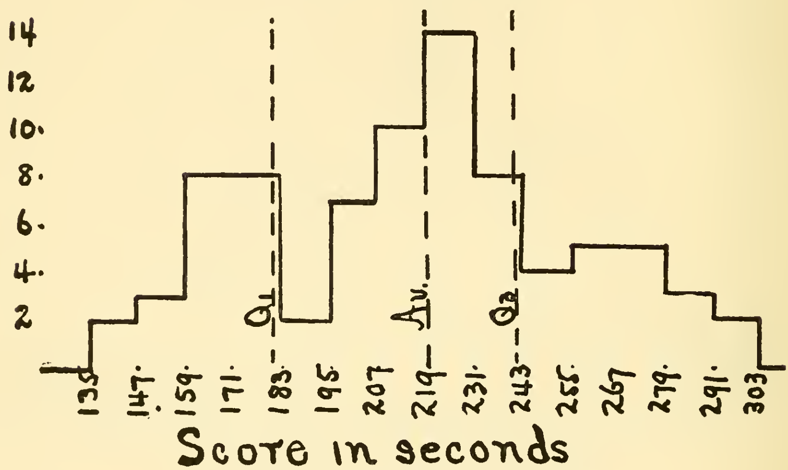
QUARTILE RANGE

I	II	III	IV
24	15	14	43

$$\frac{Q}{S.D.} = .77$$

y–measures are the frequencies.

FIGURE 8
TAYLOR TEST DISTRIBUTIONS



S.D.	$3.17 \times 12 = 38.04$	
Average	215.7	$P.E._{av}$ 2.87
Median	219.	
Q_1	181.5	
Q_3	240.	
Q	29.25	
A.D.	30.9	
$P.E._{dis}$	25.65	
Skewness	—.26	

QUARTILE RANGE

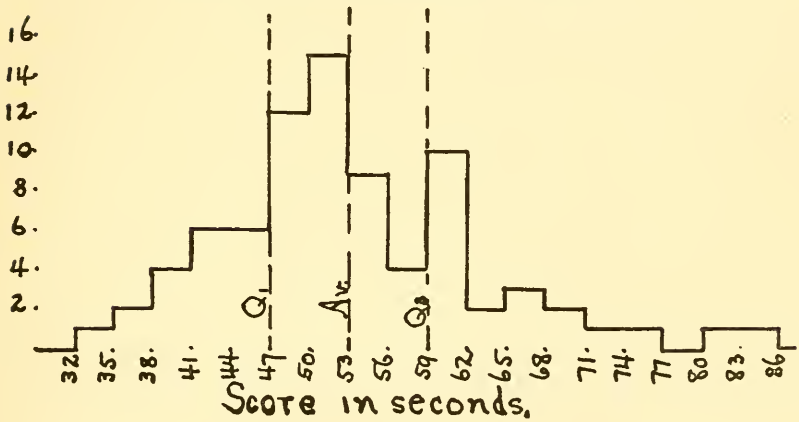
I	II	III	IV
44	34	25	85

$$\frac{Q}{S.D.} = .77$$

y–measures are the frequencies.

FIGURE 9

COMBINED ASSOCIATION TESTS—DISTRIBUTION



S.D.	9.7		
Average	53.15	P.E.$_{av}$	.73
Median	51.		
Q_1	47.25		
Q_3	59.33		
Q	6.04		
A.D.	7.2		
P.E.$_{dis}$	6.54		
Skewness	+.66		

QUARTILE RANGE

I	II	III	IV
14	6	6	25

$$\frac{Q}{S.D.} = .62$$

y–measures are the frequencies.

FIGURE 10
TOTAL RAW SCORE DISTRIBUTION

S.D.	2.53 × 40 = 101.20	
Average	768.	P.E.$_{av}$ 7.62
Median	763.	
Q_1	694.	
Q_3	824.3	
Q	65.15	
A.D.	78.	
P.E.$_{dis}$	68.25	
Skewness	+.148	

QUARTILE RANGE

I	II	III	IV
184	74	56	344

$$\frac{Q}{S.D.} = .64$$

y–measures are the frequencies.

CHAPTER VII

THE TREATMENT OF THE TEST SCORES

What is the best criterion of speed in the learned reactions? It is obvious that no one test is a safe criterion of the speed level to which these different men belong. In some instances an individual exhibits superior speed in all the tests; for example, numbers 23 and 45 achieve a first quartile rank in each of the different tests. Usually the superior speed is selective in each individual; it appears in one test but not in another. For example, numbers 2, 9, 11, 13, 18 achieve the first quartile rank—superior speed—in three or four tests; they fall to lower levels in the other tests. Frequently an individual exhibits marked inferior speed in some one test; for example, number 25 falls to the fourth quartile rank in the Addition Test. Presumably no one of these 80 men has reached his speed limit in any one of the tests or types of reaction. Practice invariably increases the individual speed. What these tests do is chiefly this: they bring to light the individual speed level in each of the tests at this particular time. They tell what the individual does *now*. Perhaps one can go further and say that a given test locates the individual at some point in his learning curve; that one or more tests may locate him at the upper level of this curve while other tests locate the same man at lower levels. This statement is made in the light of the experimental facts of practice effects on the speed of an individual in a given function.

It is manifestly impossible to secure the absolute maximum speed of reaction for every individual in all the tests. One must take the speed conditions as the individual exhibits them at the present time. None the less must one keep in mind that what the individual does *now* may be a positive criterion of what he *can* and *will* do when given additional practice in any function or type of reaction. *His rank order then* after the period of practice may be about the same as his rank order *now* before such a period of practice. Consequently it is important to determine rather precisely *what the individual does now.* No one test tells the whole story; one must take account of several—the man's score in several tests. One must secure a composite score made up in some manner from the scores on the different tests. In the first place, one can add the raw scores

of the different tests and get the total time taken to do all the tests. Is this a sound procedure? It may be that such a composite score contains an excess of some one type of reaction and thereby handicaps some men who excel not in this but in some other type of reaction. For example, such a composite score may contain an excess of the Cross Out reactions. Does this handicap any of the subjects? Again, such a composite score may contain rather new and only semi-learned functions. Speed in the mental sense is something learned and perfected through practice. At the beginning of practice in any one function achievement in that function is relatively slow; speed in the function develops to higher levels with practice.

In other words some tests may be already weighted. If these men had had but two weeks experience with addition—were mere beginners—but did possess a normal experience in the other tests, the Addition Test would be heavily weighted. The composite made up of the score of all the tests would be excessively burdened with this load of poor speed in addition. Perhaps one can get light on this problem in the following manner. Suppose one take as a composite the total score of different teams of tests and correlates these total scores with the latent time. For example, take a composite made up of the total scores of any two tests. The following table illustrates:

TABLE 3

Correlation Between the Latent Time and (1) Individual Tests and (2) Different Teams of Two Tests.[11]

Addition	.44 ± .06	Addition and Letter Cross Out	.54
		Addition and Figure Cross Out	.57
Letter Cross Out	.49 ± .057	Addition and Completion	.51
		Addition and Taylor	.43
		Addition and Association	.47
Figure Cross Out	.51 ± .055	Letter Cross Out and Figure Cross Out	.53
		Letter Cross Out and Completion	.52
Completion	.44 ± .06	Letter Cross Out and Taylor	.41
Taylor	.28 ± .069	Letter Cross Out and Association	.47
		Figure Cross Out and Completion	.55
Association	.21 ± .072	Figure Cross Out and Taylor	.46
		Figure Cross Out and Association	.54
		Completion and Taylor	.38
		Completion and Association	.45
		Taylor and Association	.32

[11] In all cases, the value of "r" is calculated according to Pearson's product-moment formula.

This shows that the sum of any two tests yields a larger value for "r" than either test taken singly—with one exception. When the Taylor Test is added to another test, the value of "r" is reduced; that is to say, when the team consists of the Taylor Test and one other test, one of the two tests in each team yields a larger value of "r" than the two tests taken together. The correlation of the team consisting of the Taylor Test and the Association Tests is a possible exception to this rule. Again, suppose one takes a composite made up of any three tests: (1) When the Addition Test or the Figure Cross Out Test or the Completion Test is added to any two tests the value of "r" is always increased. The following table illustrates:

TABLE 4

Changes in the Value of "r" (Correlation with the Latent Time) When the Addition Scores are Added to any Two Tests

Letter and Figure Cross Out Tests	.53	Add the Addition Scores	.58
Letter and Completion Tests	.52	Add the Addition Scores	.58
Letter and Taylor Tests	.41	Add the Addition Scores	.50
Letter and Association Tests	.47	Add the Addition Scores	.53
Figure and Completion Tests	.55	Add the Addition Scores	.59
Figure and Taylor Tests	.46	Add the Addition Scores	.53
Figure and Association Tests	.54	Add the Addition Scores	.55
Completion and Taylor Tests	.38	Add the Addition Scores	.49
Completion Association Tests	.45	Add the Addition Scores	.52
Taylor and Association Tests	.32	Add the Addition Scores	.46

(2) Precisely a similar increase in the value of "r" takes place when the Figure Cross Out or the Completion Test is added to a team of any two tests. The addition of the Letter Cross Out Test has a similar but less effect, especially when one member of the team of two is the Figure Cross Out Test.

(3) On the other hand, when the Taylor Test is added to a team of any two tests the value of "r" is always diminished. the following table illustrates:

TABLE 5

Changes in the Value of "r" When the Taylor Test is added to a Team of any Two Tests

Addition and Letter Cross Out	.54	Add the Taylor Test	.50
Addition and Figure Cross Out	.57	Add the Taylor Test	.53
Addition and Completion	.51	Add the Taylor Test	.49
Addition and Association	.47	Add the Taylor Test	.45
Letter and Figure Cross Out	.53	Add the Taylor Test	.46
Letter and Completion	.52	Add the Taylor Test	.47
Letter and Association	.47	Add the Taylor Test	.43
Figure Cross Out and Completion	.55	Add the Taylor Test	.48
Figure Cross Out and Association	.54	Add the Taylor Test	.47
Completion and Association	.45	Add the Taylor Test	.44

The Taylor Test has this same effect—it reduces the value of "r"—no matter what the combination of tests is. That is, add the Taylor Test to any two tests, any three tests, any four tests, and five tests; in any case the value of "r" is reduced.

Furthermore these correlations bring to light more or less definitely the diminishing increment of yield as one test after another is added to a given team of tests. This appears to be a persistent characteristic of any team of tests (HULL). The following figures illustrate this phenomenon: (1) The correlation of Latent Time and Addition is .44; Latent Time and Completion is .44. (2) The correlation of the Latent Time and Addition plus the Completion Test is .51. (3) The correlation of the Latent Time and Addition plus Completion plus Letter Cross Out Tests is .58. (4) The correlation of Latent Time and Addition plus Completion plus Letter Cross Out plus Figure Cross Out Tests is .60. But the time soon comes when the addition of another test ceases to increase the value of "r." The increment of yield in the value of "r" is strikingly reduced when the third test is added. In fact the team of three tests consisting of Addition, Figure Cross Out and Completion Tests yields close to the maximum correlation of the tests with the Latent Time. When the Letter Cross Out Test is added, the value of "r" appears to increase from .59 to .60.

So far as correlation can throw light on the matter these four tests exhibit a normal situation: (1) Each one adds something to the value of "r" (when correlated with the latent time). (2) A diminishing increment of yield in the value of "r" takes place as the number of tests is increased. (3) "r" reaches a maximum value when the team consists of four tests—very close to the maximum when the team consists of three tests. The addition of the Taylor Test always reduces the value of "r." Hence this test must be heavily weighted at the outset—in the raw scores. The following is submitted as at least a partial explanation of this initial weighting. The directions for this test were perfectly clear; at any rate each man said he understood perfectly what to do. In every instance the resulting performance showed that the man had the directions well in hand. Nothing was said in the directions about the method in doing the test. Speed in the test consists to a considerable degree in having several consecutive numbers always on hand—in mind so that the hand can be kept moving from one number to another in relatively quick succession.

Suppose, for example, this man makes a line to "2"; then he stops and hunts for "3"; then makes a line to "3"; then stops and hunts for "4"; draws a line to "4"—and so on. This is a very plodding, hand-to-mouth method. The long and numerous stops of the pencil take time and bring about more or less confusion. The subject becomes aware of delay and finds it increasingly difficult to locate the next number.

Several subjects did this very thing—chiefly the men with the large scores on this test. They never discovered any plan to increase their speed. They habitually looked only for the next consecutive number. Other men discovered that they could just as well go in search of 2, 3, 4 or more consecutive numbers and have them on hand. Thus the pencil was kept going rather steadily; there were few if any pauses. Other men started at the very beginning on this method; they constantly had several numbers on hand ahead of the immediate pencil movement. They looked ahead and prepared the way well in advance. All these men were well equipped with "intelligence," but the fact remains that they did not make full use of it. At least this is true for many of them. One might say that in some of these men the psychic factor of foresight has not become a working habit. Change the situation very slightly and there is little or no foresight. Probably they can use foresight but they habitually do not—at least not in the present situation.

Another individual variation comes to light in the performance of this same test. The directions said clearly "take the shortest distance between two numbers." The men invariably asked about this. They distinctly understood—said they did—that they were to make a straight line from one number to another consecutive number. In a few cases some men did not do this; they went from one number to another in a roundabout way, and tried to escape passing through another number. They were immediately set right. Thus in every instance the subject knew exactly what to do. But the speed of movement in passing from one number to another was notably different in different men. Suppose one number is at the top of the sheet while the next consecutive number is at the bottom of the sheet. The subject knows exactly what to do and where to go and how to do it. Yet some men take as much as one second in making the line; other men make the line in a flash. It is estimated that the time taken in this excessive slowness may

be as much as a full minute during the performance of the test. Presumably this is a habitual matter. Perhaps there is excessive carefulness which may have spread beyond the limits of some other situation into this one. The man may fail to perceive that he can move fast in this particular instance. At any rate this factor must contribute considerably to the wide difference in the individual's quartile location in this test.

One can examine the problem of weighting from another angle. Different tests exhibit different amounts of scatter or dispersion. Consequently one test may influence the composite score more than another when the composite is made up of the raw scores. The composite score ought to be representative; it ought therefore to be free from special stress and burden from any one test. When one adjusts this variability, it is presumed that each set of test scores has about the same weight or influence on the composite score. Thus one weights the raw scores and gets a new composite; is the weighted composite any more reliable than the raw composite score? ANDERSON tested out several methods of weighting: (1) Sigma scoring method. (2) Correlation of the test with the composite—total score of all the tests. (3) Correlating the test with a criterion outside of the tests. (4) Multiple correlation weighting. She concludes that the raw scores have as high validity and reliability as the weighted scores. Even the "best possible method"—multiple correlation weighting—does not appear to add much of anything to the reliability of the raw scores.

In spite of these conclusions it was deemed best to test out other methods of weighting. The following methods were used:

1. *WEIGHTING THE SCORES ACCORDING TO THE VARIABILITY OF THE DIFFERENT TESTS*

The purpose here is to equalise the spread or dispersion of the different test scores; the spread in one test ought to be about the same as the spread in another test. The evidence for this variability is found in the standard deviations of the different tests. One makes the different standard deviations approximately the same or similar in size; then uses the same multiplier or divisor with each of the scores on each test. The standard deviations of the present tests are treated as follows:

TABLE 6

The Standard Deviations in the Different Tests; Corrections to Make the Variability Constant in Each Test

Addition	*Letter Cross Out*	*Figure Cross Out*	*Completion*	*Taylor*	*Combined Association*
30.72	17.19	32.64	18.41	38.04	9.7
Divide each S. D. as follows:					
5	3	5	3	6	1½
Then one has a new set of S. D.'s					
6.14	5.73	6.53	6.15	6.34	6.47

Thus the standard deviations are made approximately equal; when the treatment is applied to the different tests—individual scores changed by the appropriate divisor—the spread or variability is about the same in each test. Thus one divides each Addition Score by 5; each Letter Cross Out Score by 3 and so on.

2. *CONVERT THE DIFFERENT TESTS INTO A COMPARABLE SERIES*

(Hull's method)

According to this method one converts the different scores into a standard normal distribution in which the scores shall range from 0 to 100 with the mean at 50. 3.5 sigma usually takes care of all spread or variability above or below the average; hence $\frac{50}{3.5} = 14$ which is the standard deviation of the new distribution. The new individual scores are computed according to the formula $X = K + SX_1$. S is a ratio between the S.D. of the new distribution and the S.D. of the given test; $S = \frac{14}{\text{S.D.}}$ K is a constant found by the formula 50 —(Average of the distribution $\times$ S) in the given test. The values for S and K in each test are as follows:

TABLE 7

Figures Used in Converting the Raw Scores into a Comparable Series

	Addition	*Letter Cross Out*	*Figure Cross Out*	*Completion*	*Taylor*	*Association*
S	.45	.81	.43	.76	.368	1.44
K	—6.6	—24.8	—21.1	—39.9	+29.38	—26.53

The results of using these two methods of weighting and comparison with the raw scores are as follows:

TABLE 8

Correlation of the Latent Time With the Individual Tests When Different Methods of Weighting are Used

	Raw Scores	*Scores Adjusted According to Variability*	*Scores Converted into Comparable Series*
Addition	.44	.43	.45
Letter Cross Out	.47	.49	.44
Figure Cross Out	.51	.46	.55
Completion	.44	.42	.50
Taylor	.28	.29	.29
Association	.21	.26	.25

The correlation between the raw scores and the scores adjusted according to variability is .96; between the raw scores and the scores converted into comparable series the correlation is .97. The correlation between the two weighted scores is .999.

According to this examination of the problem of weighting, the composite secured by adding the raw scores has about the same relation to the latent time as either of the weighted scores. Very considerable labor is involved in the weighting and nothing is gained in terms of accuracy and soundness of the composite score. Hence the raw score composite is adopted as giving a satisfactory "picture" of the individual's speed of performance in the learned reactions. The relation between the total raw score—all tests—and the latent time is, "r" = .59 ± .049. Since the Taylor Test tends to pull down this value of "r," the use of a team of 3 or 4 tests tends to slightly raise this correlation—up to .60 or .61. The fact that a team of 3 or 4 of these tests yields practically the same value for "r" and the fact that weighting the tests according to variability and according to HULL'S method does not materially alter the relationship between the test scores and the latent time—these facts are made use of in the construction of the Regression line.

CHAPTER VIII

Certain Physical Speed Mechanisms are Active During the Latent Time of the Reflex. These Mechanisms Transmit a Stimulus from One Point to Another Point Within the Nervous System. Relative Importance of these Physical Mechanisms in Determining the Quickness of Performance in the Tests. Relative Importance of Mental Speed Factors in Determining This Quickness of Performance on the Tests

The latent time in this particular stretch reflex—the Gastrocnemius muscle—differs in different individuals. So far as these 80 men are concerned, this appears to be an established fact. This latent time is consumed in transmitting a stimulus from one point to another point within a section of the nervous system of these different individuals. In many ways this section is a representative sample of the individual nervous system. It includes muscle end organs, afferent and efferent nerve fibers, synaptic junctions, neuromyal junctions and prespinal centers. The fact of difference in latency means that this section of the nervous system transmits a stimulus at a different velocity in different individuals.[12] A brief latency

[12] This conclusion is supported by evidence from other courses. (1) There is the experimental work of Carlson culminating in the conclusion that the most rapidly contracting muscle is attached to the most rapidly conducting nerve. This fact comes to light in the present experiment. At the beginning of the inquiry the myograph was driven at a high speed. This speed recorded some reflexes perfectly; in these cases, the latent time was brief. In other cases the reflex record was much spread out; the angles at the junction of the latent time period and the beginning of the muscle response were so large that accurate measurements were very difficult or impossible; these cases exhibited a long latency. It is likely that, with the myograph running at a high speed, the reflex record of a slow individual would tend to approach a straight line. (2) There is the experimental work of Lucas, Hill, Lapicque and Nernst, culminating in the exact measurement of the time factor in excitability—chronaxie—and the expression of the excitatory process in mathematical terms. The chronaxie, in this gastrocnemius nerve-muscle unit, differs in different individuals. Therefore the velocity of conduction differs. (3) There is the recent conclusion of Sherrington (*PRS*, 100B:448—1926) that the dominant factor, in individual variability in nerve muscle reaction, is functional. The source of this functional variability is chiefly in the nerve centers. Excitability is a functional factor. When the excitability is increased—chronaxie reduced—the reaction to a constant stimulus is greatly increased. (4) Since the present report went to press, additional support of the above results has appeared. Tuttle, Travis & Hunter (*AJP*, 82:99) using a stretch stimulus and action current, measured the latent time—from response of the muscle to the stretch stimulus to the beginning of the electrical change in the muscle—in the Achilles

means a high velocity or superior quickness; a long latency means a low velocity or slowness. These different levels of speed in different individuals characterise a native, unlearned reaction—the reflex. Presumably the latent time brings to light the individual's intrinsic speed capacity in this particular section of his nervous system. The question of immediate interest is this: is this individual intrinsic speed capacity in this section of the nervous system a purely local phenomenon? Is the same or closely similar speed also intrinsic for other parts, perhaps for all parts of the individual nervous system? Can one, on the basis of the latent time, locate an individual in a more or less definite speed level? In particular, what does the latent time tell about speed conditions in reactions which the individual has learned?

Suppose we set forth this problem in the following manner:

A. A totality of factors is active in producing the varying length of the latent time in different individuals. This latent time is consumed, chiefly, in the movement of the stimulus from one point to another point within the nervous system. Quickness or slowness in this movement—brief or long latent time—centers primarily (1) in the velocity of the nerve impulse; (2) in the number of nerve fibers in action. The stim-

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Tendon reflex in 8 subjects; this latent time ranged from 25 to 38 sigma. L. E. Travis (*Science*, Jan. 13, 1928) measured the latent time in the Patellar reflex in 40 subjects. He used a stretch stimulus and the action current; the latent time is the period between the response of the muscle end organs to the stretch stimulus and the moment of the electrical change in the muscle. He made 8 records for each subject; the latent period ranged from 11 to 27 sigma. He compared this latency with intelligence as measured by the Otis Higher Examination form A and found a correlation of .87.

There is considerable evidence that electrical response in the muscle takes place before the change of form. Fulton (*Quarterly Journal of Experimental Physiology*, 15:349) stresses the period of "true latency." The action current reaches the muscle, but for about 2 sigma the muscle remains unaffected by this stimulus from the motor nerve. Furthermore, there appears to be a period of rigidity; the muscle does respond to the motor nerve stimulus, but for about 4 sigma it is unable to change its form owing to the excessive rigidity which sets in immediately. Sanderson (*JP*, 17:117) found that the mechanical thickening of a given point in a muscle occurs about 3 sigma after the stimulus is applied to that point. In all voluntary action this period of "true latency" and initial rigidity ought to be reckoned with; such items are essential components in the speed of reaction in such functions as addition with pencil and paper. Suppose one adds 4 sigma to the figures which Travis reports. Then the latency in the Achilles reflex in his 8 subjects ranges from 29 to 43; in the Patellar reflex, from 15 to 31. It is well known (Dodge) that the latent time in Patellar reflex is briefer than that in the Achilles. The figures which Travis reports for the Achilles reflex harmonize well with the figures in the present report. It is noteworthy that Travis found in his 40 subjects that the slowest latent time was 2½ times larger than the most rapid. In the present report the slowest latent time is 3 times larger than the most rapid.

ulus must be adequate; a single active nerve fiber has no special value no matter how fast the nerve impulse travels; there must be a certain number of nerve fibers in action in order to set off any response. Under accurately controlled conditions, where the external stimulus is instantaneous, an increasing number of active nerve fibers means diminishing length of the latent time (SHERRINGTON 7, 8). (3) In the frequency of nerve impulses; how many pass a given point within a given time? This frequency subserves the phenomenon of summation at synaptic junctions, at neuromyal junctions and at the muscle fibers. A high frequency is associated with a brief latency; low frequency with a long latency (FULTON 2; SHERRINGTON 7).

B. A totality of factors is active in determining the time which each individual consumes in doing each test.

C. Some factor or factors are active *only* in the learned reactions—the various tests. Perhaps one can say also that some factors or factor is active only in the unlearned reactions —the reflex latent time.

D. Some factor or factors are active in both types of reaction, learned and unlearned. Examine the figures in Table 2; fluctuation in the speed of performance in the tests runs more or less parallel with fluctuation in the length of the latent time or speed of movement in the reflex arc. The value of "r" in the correlation is a measure of these concomitant speed changes. In Chapter V, attention was directed to the fact of similar elements in the two types of reaction, learned and unlearned. These elements are (a) *Structural;* excitatory mechanisms, nerve fibers and synaptic junctions. In the tests as well as in the reflex arc, a stimulus is transmitted from one point to another point within the nervous system. At least, this is true for the motor side of the learned reactions where the stimulus is transmitted from the cerebral cortex to the arms, hands and fingers. (b) *Functional;* this includes the velocity and frequency of nerve impulses and the number of nerve fibers in action, in which these impulses are travelling at any one moment. Doubtless these physical speed mechanisms in the nervous system are chiefly responsible for the length of the latent time in the reflex. The essential objective in this research is to throw some light on the value of this latent time as a criterion of what the individual can do in strictly mental reactions. Hence the questions: *How important is the influence of these physical speed factors in determining the time an individual consumes in his performance of the tests? How much do the physical factors contribute? How much do the strictly mental factors contribute?*

In the first place, the sphere of influence of the physical mechanisms *centers in the single reaction, movement or mo-*

tion. In the reflex the nerve impulses and allied mechanisms determine the time consumed in transmitting a stimulus, or tendency to excite, to some distant point; that is, from receptor to effector organs. A similar transmission takes place in the test. For example, how soon after a given signal does the individual write the figure "9"? A large part—perhaps the greater part—of this time is consumed in the transmission of the stimulus, which is set in action at the signal, from one point to another point within the nervous system. Velocity of nerve impulses goes far to determine the quickness or slowness of such a reaction. It is to be expected that when the nerve impulses travel from one point to another point at a high velocity, the individual reacts quickly; his movement is "quick"; the stimulus reaches the muscle or effector organ in a very brief space of time. The intensity of the stimulus within the nervous system also influences the quickness of reaction. For example, summation at synaptic junctions in reaction time—light and sound stimuli—greatly augments the quickness of reaction. Light alone elicits a conducted tendency to excite or set in action some effector organ. The union of light and sound stimuli makes this conducted tendency much more intense; the frequency of nerve impulses is increased; the number of active nerve fibers is greater. In other words, one can make this reaction or movement—write the figure "9"—rapidly or slowly according to the intensity of effort or concentration of attention. The physical speed mechanisms possess a certain range of capacity for speed. At the same time this range has rather strict limits. In spite of the summation of light and sound stimuli, one man's reaction continues to be relatively slow, while another man's reaction continues to be relatively fast (JENKINS).

This transmission of the stimulus, or tendency to excite, from one point to another point within the nervous system takes place in each reaction, movement or motion; for example, a single movement in the process of laying a brick, the movement or movements in writing the figure "9" and crossing out a "2." Furthermore, these physical speed mechanisms are active and perhaps chiefly responsible for the quickness or slowness of a single stroke of attention. Crossing out a "2" involves a stroke of attention, but the strictly motor element stands out pretty prominent. The fixation pause in reading language units and numerals is a single stroke of attention.

The strictly motor element may not always be so prominent in the fixation pause as it is in crossing out a "2." Nevertheless there appears to be more or less overt response of motor speech mechanisms. In reading numerals the fixation pause may be of long or short duration; long, for example, when the fixation covers 3 or 4 numerals, and short when the fixation covers a single numeral. Apparently also the duration of any fixation pause may be greatly reduced through practice (TERRY). When one reacts to a single letter, there is a single stroke of attention or fixation pause; when one reacts to a single word, there is a single stroke of attention or fixation pause. But the reaction time to a single letter appears to be the same as the reaction time to a single word (CATTELL). The fact of the matter is this; these physical speech mechanisms influence the speed or quickness of a single movement, motion, stroke of attention. This stroke of attention may consist in copying "9" or in adding 7 and 2 or in multiplying 3 and 3. In each case the end result is the same—writing "9." In each case there is a reaction to a stimulus. Presumably the stimulus to the effector organ travels just as far in copying "9" as in multiplying 3 and 3; the stimulus to the effector organ travels just as far and the time consumed is just the same when the reaction is to a single letter as when the reaction is to a word. In reading, a word is of greater value than a letter; the word accomplishes more—enables one to read more rapidly. These physical mechanisms are not concerned with what the stroke of attention accomplishes. So far as they are concerned one stroke of attention is the same as any other; for example, from the physical mechanism standpoint a stroke of attention to a letter is exactly the same as a stroke of attention to a word, for in each case the stroke of attention consumes exactly the same time.

On the other hand, *the sphere of mental quickness centers in (1) accomplishments, purposes, ends and (2) means for achieving the end.* "Means" here is essentially a time factor; different types of "means" accomplish a result in different amounts of time. Quickness in accomplishment depends on the means which the individual uses. From the point of view of physical movement the child takes short steps; the adult takes long steps. Hence the adult moves faster; he covers more space in a given time; he covers the same space in less time. But the limit to the length of the step or stride in these physical movements is soon reached. In mental quickness the limit

to the length of the stride is scarcely ever reached. One can express a given idea tersely in 5 words or verbosely in several hundred words. One handles numbers by counting, by adding and by multiplying. In counting one moves along with "baby" steps or strides; in multiplying one takes "league" steps. When one uses multiplication he achieves the desired result hundreds of times more quickly.

Hence come two fundamental questions in mental quickness. Given the purpose, end or result to be accomplished; what means or tools are on hand for achieving this end? (1) *How many movements?* Suppose, for example, that the end result is the laying of a single brick in the vocation of bricklaying. One man (A) uses 18 movements; another man (B) uses 4 movements. Each man accomplishes exactly the same result—laying one brick. The speed or quickness of a single movement is a minor factor in speed of bricklaying. It is chiefly the number of movements which determines the speed of accomplishment. In fact, (A's) latent time may be considerably less than (B's) and yet (A) will consume much more time in laying the one brick. In (A's) case nerve impulses transmit the stimulus to the effector organs—the muscles—in each movement; this same transmission is repeated 18 times. In (B's) case this stimulus transmission is repeated 4 times. It is as though (A) runs 18 miles while (B) runs 4 miles to reach exactly the same destination.[13]

(2) Mental speed or quickness is concerned not so much with a reaction per se (movement, motion, stroke of attention) as with what may be called, *the value of the reaction. What does the reaction yield or accomplish in relation to the desired end? What is the length of the stride?* In bricklaying, 13-15 movements were found to be useless; they contributed nothing to the end result. But, in the sphere of mental quickness, a given result may be accomplished by several reactions of one type or by one or two reactions of another type. In each case all the reactions are essential. The time taken to accomplish the result depends on the nature of the reaction. Take this sentence: "Put the book on the table." One can spell out each

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[13] This illustration depicts GILBRETH'S experimental findings. Speed in bricklaying depends not so much on quickness of motion as on the number of motions. He found that men were using 12-18 movements in laying a single brick; two-thirds of these movements were useless. These men were SLOW bricklayers although quick in making a single motion. 2, 3, or 4 movements accomplished the SAME result many times more quickly.

word and eventually reach the meaning of the sentence; one reacts or gives a stroke of attention to each of the 20 letters; reacts to each word after spelling it and finally reacts to the sentence as a unit. On the other hand, one can react to the sentence as a unit immediately; one or two or possibly three fixation pauses reach the direction which the sentence contains. The end result is the same in each case. One can reach this end result by reacting 27 times or by reacting 3 times. The time of the individual reaction is about the same; at any rate, the reaction time to a letter is the same as the reaction time to a word. But the reaction to the larger unit has greater value; it accomplishes more; it reaches the end result more quickly.

These questions—How many reactions (movements, motions, strokes of attention) ? What is the value of the reaction?—are of prime importance in determining the individual speed in addition. Addition itself is a "higher" type of reaction. One can handle numbers by counting; one can count with considerable speed. But necessarily counting is a slow method, no matter how fast one counts. When one counts, he uses a large number of reactions to achieve a given result. Be his latent time ever so brief, his quickness in each of 8 individual reactions cannot reach the end result as quickly as a single reaction in 6 + 2. In addition, the distinctly *mental speed* factors are (1) *span of perception.* With a single stroke of attention one can fixate 1 or 2 or 3 or even more figures. TERRY reports that in reading numbers in a row—saying them aloud, the average span is 2.38 figures with a range of 1.88 to 3.40. In language the same observer reports an average of 6.47 words per span with a range of 5.18 to 7.90. CATTELL reports that after a very brief exposure a subject recognizes 3-6 figures; 2-5 letters; 1-4 words. Evidently the recognition span—presumably a single stroke of attention—is pretty large. WARREN has additional evidence in support of the proposition that subjects such as the men in the present experiment can readily grasp, recognize, apprehend as many as 3 figures in a single stroke of attention. WARREN is studying reaction time in perceptive counting; that is, given 1, 2, 3 or more dots on a card, expose the card for a very short time; how long does it take to apprehend that there is one dot, that there are two dots, that there are three dots, and so on? The following reaction time figures illustrate—figures are in terms of sigma:

TABLE 9
Reaction Time in Perceptive Counting

Number of dots	*Subjects:* *A*	*B*	*C*	*D*
1	407	523	429	497
2	415	532	419	416
3	481	575	466	514
4	620	652	600	613

(1) Three subjects apprehend 1 or 2 dots in about the same time. For example, a single stroke of attention consumes 429 sigma in apprehending "1"; the same man apprehends "2" in 419 sigma. One subject—Warren (D)—apprehends "2" in much less time than he consumes in apprehending "1." (2) Three subjects consume longer time in apprehending "3"—longer than they consume in apprehending "1" or "2." Subject D consumes 98 sigma more in apprehending "3" than he consumes in apprehending "2" but it takes him about the same time to apprehend "3" or "1." Ordinarily, according to Warren, perceptive counting is limited to 1, 2, or 3; these are the limits of a single mental act or stroke of attention. (3) Reaction to "4" is a more complex act; the subject apprehends "3" as a unit and then reacts to the extra unit; apparently there is no additional eye movement. (4) the limit of progressive counting—by successive units—without eye movements is "5"; that is, one can apprehend that there are 5 dots with no eye movements but with more than one mental act or stroke of attention.

The subjects in Warren's experiment were intellectually superior—perhaps not unlike some of the 80 men in the present experiment. It is likely, therefore, that some of these 80 men can apprehend 3 figures in a single stroke of attention as quickly as they can apprehend one figure; this apprehension of 1 or 2 or 3 figures takes place in a single mental act and there are no eye movements. This capacity is part of their original nature. Some of these 80 men can apprehend 2 figures as quickly as they can apprehend 1 figure; their apprehension of 1 or 2 figures takes place in a single mental act or stroke of attention; to apprehend 3 figures they may use no eye movements but they do use an additional mental act. Likewise this capacity to apprehend 2 and no more in a single mental act is a part of their original nature. Perhaps, also, some of these 80 men are limited by original nature to the apprehension of a single

figure in a single mental act. In the presence of 3 figures they react to one figure and then to each additional figure with additional mental acts; there may or may not be additional eye movements.

Suppose one assume (1) that the quickness of a single mental act or stroke of attention has a physical basis in the velocity of nerve impulses; (2) the velocity of nerve impulses in certain 3 individuals is the same. If in one of these three individuals a single mental act can apprehend 3 figures, in another individual 2 figures, and in the third individual one figure only, one has a variable which is relatively independent of any physical speed mechanism such as conditions the length of the latent time. The mental act which apprehends 3 figures, in adding the three single place figures, has greater accomplishment value; it reaches the end result—the sum—more quickly than the mental act which apprehends one figure only. It seems very likely that these different speed capacities—to apprehend different numbers of figures in a single mental act —actually characterise original nature of these 80 men.

(2) *Duration of the Individual Pause.* The span of perception varies the speed in adding because, for example, the single stroke of attention which apprehends 3 figures contains more, has greater accomplishment value, reaches the end result more quickly than the single stroke of attention which apprehends 1 figure. The length of the individual fixation pause or stroke of attention also varies the speed in adding. The individual stroke of attention may be long or short in duration. To a considerable extent the duration of the individual pause is independent of the number of figures which the individual pause apprehends. The results in Warren's experiment illustrate this. The following illustration is taken from studies in reading (language) but it is applicable to numbers and aptly illustrates the present point:

TABLE 10

The Number of Fixation Pauses; The Duration of the Individual Pause in Reading (Terry)

	Pauses per Line	*Duration of Each Pause*	*Reading Time per Line*
Group A (5 adults)	6.05	5.37	32.52
Group B (45 adults)	6.50	7.70	50.08
Time unit = $^1/_{25}$ of a second			

The subjects in "A" read much faster than the subjects in the other group; "faster," in the sense of achieving a result very quickly—much more quickly than group B. This "result" consists in getting the thought from the printed line, sentence or paragraph.

Another illustration throws light on individual methods in adding:

TABLE 11

Number of Fixation Pauses and Length of Each Pause in Adding 12 Singles Place Figures. (Buswell)

	Number of Pauses	*Range in Duration of Each Pause*	*Average Duration*	*Total Time Spent in Adding the Problem*
		Time Unit $= 1/25$ *sec.*		
Subject A	11	6 to 24	14	$6\frac{1}{15}$ seconds
Subject B	10	7 to 18	9.8	$3\frac{23}{25}$ seconds
Subject C	11	6 to 18	12.2	$5\frac{2}{5}$ seconds
Subject D	9	12 to 69	35.	$12\frac{16}{25}$ seconds
Subject E	17	4 to 59	25.	$17\frac{4}{25}$ seconds
In another but more difficult problem—more difficult combinations—same number of single place figures—the record for the first three subjects is as follows:				
Subject A	10	10 to 88	38.2	$15\frac{7}{25}$ seconds
Subject B	9	7 to 28	16.	6 seconds
Subject C	14	7 to 56	22.1	$12\frac{2}{5}$ seconds

Subjects A, B, C are college students; subjects D, E are elementary school students. According to the above superior speed in adding consists in (1) Few fixation pauses; the single span of preception covers more "ground"—has greater accomplishment value. (2) Brief duration of the individual pause. (3) Regularity in the duration of the different pauses. All these factors must be in action. Subject B uses few pauses, brief duration in each pause, and regularity in the duration; in the first problem, 9 pauses ranged in duration from 7 to 11; one pause only was larger. Subject D used few fixations but the fixations were very long; this is to be expected, for this subject, being an elementary school student, has not developed his speed; further practice will doubtless reduce the length of the fixation pause.

Many of the men in the present experiment are making use of these higher types of reaction; the individual fixation pause includes more, has greater accomplishment value and its duration is brief. The time taken in the performance of the Addition Test is frequently less than 90 seconds. If one takes account of the time spent in moving the hand from one problem

to another and from the end of one row to the beginning of another row of problems, the actual time spent on each problem is short—about one second. Other men exhibit exceptional slowness. This is due among other things to (1) The small accomplishment value of the individual fixation pause; there may be several pauses on a single figure. (2) The individual pause occupies a relatively long space of time. (3) Adding 3 single place figures is frequently honeycombed with a number of perfectly useless habits; when a man adds he goes through all these habits; this takes time.

Some examples will illustrate. One man, number 41, was observed to be very slow in his addition. He was questioned about it. He admitted that he always verified each result even in such an elementary problem as adding $3 + 4 + 1$. Doubtless a long and involved problem or a long column of figures does demand some verification. But in these simple additions on this Addition Test this verification is a time-consuming habit —a useless habit. It makes the man distinctly slow while his nervous system is competent to do rapid work. Take number 25; he admitted that he did not know some of the combinations. This means that he broke up some combination into smaller units or he paused an exceptionally long time at the "hard" combination; perhaps also he used other strictly individual methods. Thus a single function such as $9 + 7 + 5$, becomes literally honeycombed with a lot of useless movements.[14]

What are the mental speed factors in the Cross Out Tests? It is significant that there appears to be less opportunity for improvement on such tests than on Addition Tests (RACE). In terms of product per unit of time one reaches an upper limit of speed more quickly. Recent experiments (BOOK) show that the champion typists in the world are notably superior in voluntary motor ability such as the rate per second at which one can move the hand using the wrist as a hinge. Practice appears to have but slight influence in perfecting this movement. Likewise in tapping there appears to be a minimum of improvability. The reaction on the Cross Out Tests is not unlike these types of motor ability. When one crosses out "A" he

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[14] BUSWELL quotes individual methods actually used in managing difficult combinations. One boy was slow in adding 9, 7, 5. "In working this problem he said to himself: '$9 + 2 + 2 + 2 + 1 = 16$ and 21.' Another boy in adding 9, 7, 5 said: '9 and 3 is 12 and 4 is 16 and 2 is 18 and 2 — 20 and 1 — 21.' Another pupil in adding 4, 9, 6 explained thus: take the 6, then add 3 out of the 4. Then 9 and 9 are 18 and 1 are 19."

makes a downward movement with the pencil; from one point of view high speed in crossing out a letter or figure consists in rapid down and back movements. The intrinsic speed in the motor part of the cross out reaction is doubtless a prominent factor in determining the individual variations. The value of "r" is larger in the correlation of the latent time and the Cross Out Tests than in the correlation of the latent time and the other tests.

None the less, improvement in speed does take place as the result of practice. Very likely "technique" is a factor in such improvement; this consists in such items as grip on the pencil and paper; adjustment of the arm and elbow; attention to the movement or to the stimulus. It appears likely, however, that speed factors of a distinctly mental nature are fundamental in determining the performance time of these 80 men. These mental factors appear to center in the span of attention; perhaps it is best to call it a certain "flexibility" of attention. In crossing out "A" one can fixate each letter one at a time and cross it out or not; then move attention to the next letter. This is a sort of "hand-to-mouth" method; attention does not move beyond the letter immediately present. With this method crossing out takes place slowly for the hand is doing nothing most of the time. (2) One can send attention on ahead and isolate "A's" in advance. That is to say, attention covers both the actual crossing out of a letter and keeping a constant supply on hand to be crossed out. Perhaps it is not so much a span of attention as the rapid movement of attention. It is possible that one could keep the hand crossing out the letter in quick succession when the attention is skilled in keeping a supply of letters on hand—isolated and ready for the "operation." This situation is not unlike the eye-voice span in reading. In a rapid reader the eye moves at a relatively long distance ahead of the voice; that is to say, at any one moment of time the point on the line which the eye is fixating is as much as 8 words ahead of the point on the line which the voice is speaking. BUSWELL reports that "the rate of reading and the width of eye-voice span increase together. There is a high positive correlation between these two factors in reading."

This examination of addition and crossing out letters or figures at least illustrates the nature of the strictly mental factors in adding and in the Cross Out Tests. Very likely the same or similar mental factors are active in the Completion

Test. The team of tests, consisting of the Addition, Figure Cross Out and Completion Test, yields a maximum correlation with the latent time. Some reasons for the failure of the Taylor Test to contribute to the correlation yield have already been given. Can one measure the relative importance of the two factors, physical and mental, in determining the performance time on the tests? However this may be, one must take account of the following situation: (1) The physical speed mechanism determines the time of a single reaction, motion, movement, or stroke attention. It governs such items as setting up action in some excitatory mechanism and sending out nerve impulses; transmitting nerve impulses or the tendency to excite to another point within the nervous system; setting up action in some effector organ such as the muscles of the hand and fingers and the speech mechanisms. This physical speed mechanism is a part of original nature which is the foundation of speed of performance in the tests. (2) If other things were equal, this physical speed mechanism might govern the individual performance time in the tests. But these other things are never equal. Mental speed factors operate more or less independent of the physical speed mechanisms. Original nature enables one to climb up through a hierarchy of reactions. Handling numbers by counting stands at a low level in this hierarchy; one must use a large number of this type of reaction to achieve a given result. A single "high" reaction such as associating 13 with $8 + 3 + 2$ with a single stroke of attention handles the same situation with great economy of time. It is likely that these 80 men differ to some extent in ability to develop the "high" reactions; for example, they may differ in ability to apprehend 1 or 2 or 3 figures in a single stroke of attention.

These mental speed factors must be learned. Undoubtedly learning exercises a marked influence on the individual performance time. Different men stand at different levels in the hierarchy of reactions; perhaps they can reach a higher level but have not done so. Speed in any one type of reaction—be it counting or associating 3 figures with their sum—is an effect of practice or learning. It seems likely that each man, in the type of reaction which he uses, stands at a different speed level. For example, one man may count very rapidly; another man may react to 3 figures very slowly because he has not developed his speed in this type of reaction. Furthermore it may be said

that the "intellect" perceives that certain movements are useless; perceives that one can move fast at this or that place; perceives that one can move his eyes ahead and keep a supply of letters ready for the hand to cross out. But this perception may or may not take place. Useless movements persist and slow up this or that man. Vestiges of counting hang over into the strictly "addition" types of reaction. In fact, the mental speed factors present a veritable conglomerate of acquired speed abilities, each one of which is relatively independent of the physical mechanism. When one compares the latent time with this conglomerate, it is as though one were comparing the latent time with the performance time of a group of bricklayers in laying a single brick where one man uses 3 movements, another 5, another 7, and so on up to 18.

CHAPTER IX

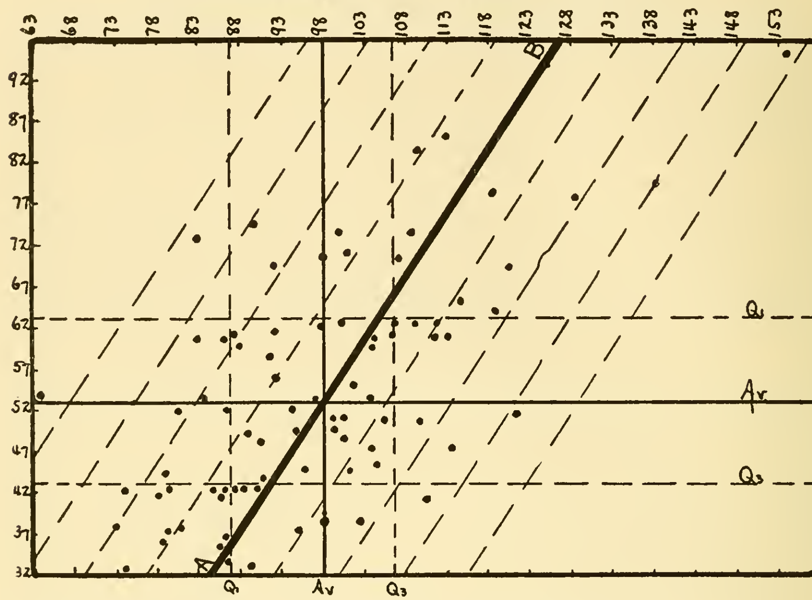
The Regression Line in the Present Problem. Significance of its Limited Prediction Value. How Much the Test Scores Depart from a Perfect Correlation with the Latent Time Measures. The Effects of Practice on the Correlation. Conclusions.

The primary purpose at work in examining the regression line is to secure evidence on the question—how much does the physical speed mechanism contribute to the performance time on the tests. In the preceding chapter it was emphasized that the mental speed factors are more or less independent variables—independent, that is, of the physical mechanism in speed of action. These mental factors in speed must be learned. Wide variations in the amount and quality of the learning greatly augment the capacity of the mental factors to vary the individual independent of the physical mechanism. The net result is that the individual quickness on the tests does not always have much in common with the intrinsic capacity for speed which the latent time is presumed to depict. Bryan stresses a similar fact when he says "no reaction time test will surely show whether a given individual has or has not effective speed in his work; very slow rates may point to slowness in all things; but rapid rates by no means show that the subject has effective speed."

In constructing the regression line in Figure 11 three tests only are used; these are the Addition Test; the Figure Cross Out Test and the Completion Test. The scores on these tests were corrected for variability on the basis of the standard deviation. The correlation of these corrected scores with the latent time is the same as the correlation of the raw scores with the latent time—"r" = .59. Furthermore these three tests yield a correlation value which is the same as the correlation of the sum of all the test scores and the latent time. The corrected scores of the three tests are small in numerical size; this makes it possible to use a class interval of 5 in both x- and y-measures. The standard deviation of the test scores is but slightly different from the standard deviation of the latent time scores. Thus one has an excellent condition for the construction of an understandable regression line.

FIGURE 11

THE SCATTER DIAGRAM. REGRESSION LINE. GRAPHIC REPRESENTATION OF THE PROBABLE ERROR OF ESTIMATE AND THE AMOUNT OF DEPARTURE OF THE MEASURES FROM A PERFECT CORRELATION



x–measures = test scores

$\sigma_x = 14.40$

$Q_1 = 87.5$

$Q_3 = 106.3$

Average = 98.

A–B = Regression line

$$x = .59\left(\frac{14.40}{13.35}\right) y = .65y$$

$$X = .65\ (y - 53.2) + 98 = .65y + 63$$

$$\text{P.E.}_{\text{est}_x} = .6745\ (14.40\sqrt{1 - r^2}) = 7.76$$

y–measures = latent time

$\sigma_y = 13.35$

$Q_1 = 43.25$

$Q_3 = 63.7$

Average = 53.2

The x–measures are the test scores of a team of three tests; this team consists of the Addition Test; Figure Cross Out Test, and the Completion Test. The raw scores are weighted according to their variability. The raw scores are about four times larger than the weighted scores. The diagonal broken lines represent 1 P.E., 2 P.E., 3 P.E., and 4 P.E. on each side of the regression line.

One can draw this line immediately by means of the equation, $x = .59\left(\frac{14.40}{13.35}\right) y$. Solving this equation, $x = .65y$. When one computes the new or estimated test scores on the basis of the equation, $X = .65y + 63$—the score form of the regression equation—one gets a pair of test and latent time measures, each of which lies on the regression line. Each of

the 80 pairs of measures, the given latent time measures and the estimated test measures, lies on this line. The new or estimated test measures correlate perfectly with the old or given latent time measures.

Thus one has two sets of test measures; the one set correlates perfectly with the given latent time measures; the other set correlates with the same latent time measures with a ratio of 0.59. Thus one has the facts for determining how much the true test scores depart from a perfect correlation with the latent time measures. One can readily compute these differences. The differences are strictly individual; some new or estimated measures are larger than the old while others are small and still others are about the same size. One can take the group as a whole and compute the departure of the group from a perfect correlation with the latent time measures by means of the equation, $P.E._{est_x} = .6745\ (\sqrt{1 - r^2})$; this gives a value of 7.76. This probable error of estimate as a single quantity takes account of all the individual departures from a perfect correlation with the latent time measures; it is the median amount of shift or change in the size of the test measures which one must make in order to secure a perfect correlation. It must be stressed that this estimated or perfect correlation "line-up," as it were, is specific to this group; it is based on what these men do now.

Do these regression line figures offer a basis for accurate prediction? Can one take a definite latent time measure and predict what the corresponding test score will be? A reliable prediction must locate the test measures in a rather precise spot. Every prediction is subject to change according to the size of the probable error of estimate. In the case of 50% of the given pairs of measures there is a departure from a perfect correlation which equals or exceeds 7.76; this is equivalent to about 31 in terms of the raw scores. A single probable error includes only 50% of the cases. If the value of the probable error is small, a distance of 2, 3, 4 P.E. is relatively small. When the probable error is large, these distances in terms of the raw score units of measurement are very large. Suppose one take the latent time of 34; the predicted or estimated score on the tests is 85. Let this estimated score read "plus or minus 2 P.E." The estimated test scores may be as much as 15 points larger or 15 points smaller than 85. The

raw scores are about four times larger than the corrected scores. Hence the estimated score is 340 plus or minus 60 seconds. But 2 P.E. include only 82.26% of the cases. When one takes account of 3 P.E. and 4 P.E., the limits within which the estimated score may lie become very great when the size of the single P.E. is large.

Why should one expect to predict? The fact that the mental speed factors operate as variables relatively independent of the physical speed mechanisms; the fact that amount and quality of learning in these mental factors differ enormously from one individual to another and in the same individual from one type of function to another—these facts ought to reduce the possibilities of prediction to a low level. Suppose one examine subjects 42, 43, 44, 45. In each case the length of the latent time is 53 sigma; thus there is no difference in the capacity of the physical mechanisms. The scores on the three tests—total scores of Addition, Figure Cross Out, and Completion Tests—are as follows:

Number 45	265
43	352
42	412
44	450

These scores are widely scattered, covering a range of 185 seconds. Subject number 45 has first quartile rank in each of the tests used in the present experiment. Number 43 has first quartile rank in Addition. In fact his score of 82 in Addition is very superior; number 45's Addition Score is 77. Evidently these two men have made ample use of their mental speed factors in Addition; they have developed reactions to large units and have eliminated all useless movements. For pupils in the 8th grade the fixed accomplishment time on this Addition Test is 180 seconds. These two men—several other men also—accomplish this same task in considerably less than one-half this time. Number 42 has a score of 146 on the Addition Test; this is very slow. But the same man has a very superior score on the Taylor Test—171. This man has no small speed ability; he must be quick in a single reaction. In performing this test in 171 seconds he must have eliminated useless movements; must have looked ahead and located several numbers in advance; must have moved fast when he saw the chance

and must have perceived the chance. Number 44 has a large score in Addition—147; a large score in Figure Cross Out—200. At the same time he has a superior score in the Letter Cross Out—74; a superior score in the Completion Test—103, and his score on the Taylor Test is exceptionally speedy—154. Hence he is not a slow man. On the contrary he must be quick in a single reaction and in some types of function has developed his mental speed factors to a high level of speed.

Thus these 4 men exhibit about the same degree of quickness in a single reaction. Their latent time is the same; each man exhibits superior quickness in some one or two or three tests. Their total scores are scattered over a wide area because this or that man is slow in some one or more tests. Presumably these men have the ability to make quick time in these tests also. The trouble is that they are not making full use of their mental speed factors; they are, for example, reacting to small units and are making useless movements or, if they do react to large units, they have not developed their speed in this type of reaction. When one tries to predict on the basis of these men's total scores, this prediction cannot fix on any one spot; the predicted score may be, for example, 265 or 352 or 412 or 450 or some other score. The predicted score must be labelled "plus or minus 5 P.E." Number 45's true score lies 5 P.E. distance from the predicted score; number 44's score is located a distance of 2 P.E. on the other side of the regression line. Prediction here is not unlike predicting speed in bricklaying when (1) the quickness of a single movement is the same in each man; (2) one man uses 3 movements, another man 7 movements, another man 12 movements, and another man 19 movements; and (3) with these different movements each man lays just one brick.

Suppose one examine number 45 in some detail. His true score on the three tests is 63—corrected for variability. The estimated score which makes a perfect correlation with the latent time measure is 98. Thus beginning with the point of perfect correlation with the latent time measures one must move out a distance of 5 P.E. in order to reach this man's actual score. 4 P.E. includes 99.3% of the cases. The chances are 142 to 1 that a measure chosen at random will fall within this distance. Number 45 is this ONE man who belongs beyond this limit. 5 P.E. includes 99.92% of the cases; the chances are 1310 to 1 that a measure chosen at

random will fall within this distance. One may say that number 45 is one man in a thousand who takes up a position so far out in the speed end of the distribution. In quickness of a single movement this man does not appear to be superior to the other men—42, 43, 44; they have the same latent time; each of the three men exhibits a speed of performance in some one of the tests which is fully as superior as that of number 45. *Number 45 exhibits a superior development of his mental speed factors.* He perceives useless movements and eliminates them and thereby augments his speed of performance. He perceives that he can move fast when making a line from one figure to another and actually moves fast. He looks ahead in crossing out figures so that his hand is crossing out a figure in rather quick succession. He has developed higher types of reaction to numbers. His physical speed mechanism does participate in determining his superior performance. But his superior mental habits have greatly reduced his accomplishment time. His physical mechanism is no more rapid than that of number 44, but his performance time is fully 75% quicker. His physical mechanism is only 50% as rapid as that of number 1, while his speed of performance is 40% greater.

Improvement through practice in functions which the tests represent is a fundamental fact. The present true test scores correlate with the latent time measures with a ratio of 0.59. Suppose these 80 men were practiced on these different functions—Addition, Cross Out and Completion, for example; one would have at the end of the practice period 80 new and true scores in each of the tests. *What would be the relation of the two sets of true scores? What would be the relation of the present regression line and the new regression line? Would the new scores exhibit a more perfect correlation with the latent time? Is the present correlation ratio relatively stable?*

At the present time there is considerable positive evidence on the actual effects of a period of practice in such functions as are used in the present experiment. Several observers conclude that improvement through practice is rooted in original nature (KIRBY, PYLE, RUCH, THORNDIKE, WELLS). The bright improve more than the dull. Changing time allowance does not alter the relative position of the subjects; that is, the extra time does not permit the dull to equal the score of the bright; a correlation of .965 between single and double time

allowance is reported (RUCH). THORNDIKE is pretty insistent that original nature is the governing factor in improvability. Those who are ahead at the start maintain and increase their lead. "The status which an individual has attained in a function from a given amount of practice is highly prophetic of the status which he will attain from any given amount of additional practice" (THORNDIKE 4). The following figures illustrate:

5 initially lowest	gain	4.7	(amount per unit of time)
7 initially next	gain	9.4	
4 initially next	gain	13.6	
8 initially highest	gain	15.2	

Thus the 8 whose initial score (score at the beginning of practice) was the highest, whose speed was greatest, gain 3.23 times more than the 5 whose initial score was the lowest. Again, given 670 college students who are practiced in adding 10 single place numbers; "the highest initial levels made the greatest absolute gain (THORNDIKE 6).

Furthermore, speed and level of intelligence (power) appear to be related (L. S. HOLLINGWORTH, HUNSICKER, RACE, PEAK AND BORING). Given, for example (1) a speed or rate test—the first two sheets of the I.E.R.[15] completions and the first two sheets of the I.E.R. arithmetical problems; (2) a power or ability test—the highest difficulty level in which 50% of the elements of that level are done correctly. The correlations between rate and level in arithmetic, between rate and level in completion, range from .39 to .61. According to the experimenter, this indicates "a consistent relationship between rate of mental work and level of intelligence" (HUNSICKER). RACE found that subjects of superior intelligence (above the 75 percentile) make a greater gain through practice in adding 10 single place numbers than the subjects of average ability (below the 25 percentile). Within the superior intelligence group those above the 75 percentile make the greatest gain. Within the average ability group those above the 75 percentile make the greatest gain. For example, in a group of college students:

Below 25 percentile;	initial score	13.875	(amount done in unit of time)
	gain	16.0	
Above 75 percentile;	initial score	38.25	
	gain	26.75	

[15] *I.E.R.* = Institute of Educational Research.

These studies measure improvability by means of a definite but limited amount of practice; they follow the subjects through the "first quarter" and perhaps into the "first half." What will happen in the "third and fourth quarters"? Ordinarily the experiments make no pretence of reaching the limits of ability. Besides, to more or less extent they are concerned with averages. The group or that part of the group which exhibits the superior initial scores will exhibit the largest average gain. But some in the group will show a large gain while others will show a small gain. On the other hand, some in the slow group will make large gains while others will make small gains. The classification on the basis of the initial score is more or less arbitrary. The experiments are "trial heats," as it were. Various facts come to light in these trials. Will the same facts continue to dominate up to the limits of maximal improvement? For example, on the basis of what the subjects do in the "first quarter," one may assume that the initial score is a sort of coefficient of original nature. Will the subjects with the largest initial scores finish the "fourth quarter"—maximum ability—with largest scores?

If one expects to practice a group of subjects through to maximum ability, several controlling factors must be reckoned with. With a few exceptions, one of which will be mentioned later, experiments on improvability make no attempt to measure or otherwise utilise these factors. An individual may make large gains for more than one reason. There are gains due to the high level of mental speed ability; there are gains due to the low level of practice at the time the initial score was made. (1) It is possible to get some light on the subjects' original nature and thereby form a criterion as to what they may be expected to do when perfecting their speed of performance in different types of materials. In the first place the length of the latent time in the Achilles tendon reflex measures the intrinsic speed with which physical mechanisms transmit a stimulus from one point to another point within one section of the nervous system; this measure points to a similar intrinsic speed in other parts of the nervous system of the same individual. (b) The I.Q. tells something about intrinsic speed conditions; children whose average I.Q. is about 150 exhibit a considerably higher rate of tapping than children whose average I.Q. is about 100 (HOLLINGWORTH). (c) The rate of to and fro movements of the forefinger, wrist, forearm and

upper arm bring to light intrinsic speed conditions (BOOK). Such measures bring to light the individual quickness in a single movement. Original nature in the mental speed factors is much more difficult to "reach." One can measure the individual span of attention and span of perception, assuming that these may not be precisely the same thing. Foresight appears to be a factor in many of the tests such as the Cross Out Tests, but it defies any sort of measurement.

(2) What is the state of the subjects' learning in this or that type of material at the time of the initial score? The initial score may be considered as a point on a line; this line or curve measures the distance from zero ability to the maximum ability in the given type of material or function. The amount of the individual improvability is the distance from this point to the limits of his ability in the given function. The size of the initial score is, in some respects, a measure of the relative position of this score on a scale of increasing quickness on the one hand and increasing slowness on the other hand. For example, in the Addition Test, a score of 140 and beyond may be set down as characterizing slowness; a score of 45-50-60 indicates superior speed. At any rate the variable condition at the time of the initial score ought to be measured and controlled in some manner. Ordinarily the studies in improvability make no attempt to measure this relative position of the initial score (BUSWELL, 3—page 112).

(3) How much unlearning? For example, the man who habitually breaks up various combinations in addition must unlearn these useless habits before he can forge ahead in his positive improvement in speed. Many subjects may make no improvement because of these accumulated parasitic habits. BUSWELL (1) gives a list of 28 such habits. Such initial conditions of learning differ in different individuals. The fact that a man has a superior score in some one or more tests but a poor score in other tests is evidence that the poor score is due chiefly to defects in learning. This is illustrated in the discussion of subjects number 42, 43, 44, 45. A study of fixation pauses, their number and duration, would throw a lot of light on the state of the individual's learning at the time of the initial score.

(4) The type of mental function which the individual uses in his experiment also cooperates in determining the amount of improvement which the subjects will make. When the

function is chiefly motor, such as the rapid to and fro movements of the arm, the effect of practice is close to zero (BOOK). When the function is relatively simple, such as crossing out letters and figures, the improvement is larger than in the motor functions but still relatively small. Complex functions such as adding several single place figures offer the greatest opportunity for augmenting the speed of performance (RACE). The ability to improve and increase speed appears to consist chiefly in the ability to set in action higher types of reaction; these are the distinctly mental speed factors.

(5) *The most important factor in securing improvement through practice is incentive or drive.* PHILLIPS gives sound evidence that subjects whose initial ability is high make the greatest gain *only when the practice or drill is very intense. When the drill is that of the daily work of the class, the group whose initial ability is the lowest makes the best gain; the gain of the low ability group may be two or three times greater than the gain of the superior group.* In other words, the superior group has the intrinsic capacity; but having capacity is one thing; setting the capacity in action is another and different thing. Only when the drive is very severe—the competition intense—only then is the superior capacity set in action. BRYAN stresses a similar idea when he insists that, in rising to high level types of reaction in telegraphy, it is the supreme effort that brings the results. The problem is how to enlist the supreme effort. It is entirely possible that ten men may have the same potential capacity; yet the actual scores at the beginning of a period of practice will be distinctly "jagged"; that is, the scores will be ten peaks of different heights. After a period of practice there will be the same ten peaks but two or three men, very likely those whose initial scores are superior, will rise to superior heights. BANKER develops the point of view that competition exercises a differential effect. Under its influence speed variations depart from the normal probability type in that the skew from symmetry may be as much as 8 times the probable error—beyond the range of chance errors. Within limits competition stimulates to greater effort. But some men give up trying and fall behind; that is, a reversal takes place when they do not secure and maintain the lead. On the other hand, the stimulus to competition acts on other men in only one way; the su-

preme effort to surpass is always active; there is no reversal. The situation may be a losing one; none the less the incentive to surpass is always present in full force. In consequence of this individual action of incentive (motivation, interest, drive, ambition) different men will exhibit different amounts of improvement at the close of any period of practice—even when all other things are equal.

HOLLINGWORTH practiced 13 subjects to the absolute limits of capacity. Progress up to the limit is illustrated by the relation of the Addition Score at different points in the practice period with the final score—in this experiment, the 175th trial:

TABLE 12

Correlation of the Addition Score, at Different Points in the Practice Period, with the Final Score in Addition. (Hollingworth)

Initial	5 *Trials*	25 *Trials*	50 *Trials*	80 *Trials*	130 *Trials*
.154	.193	.874	.869	.873	.962

Thus the initial ability is a long distance from the final ability. In color naming and cancellation the distance is not so great; the correlation of the initial score with the final score in color naming is .68; in cancellation the correlation is .67. In the Addition Test there is a marked jump in the relation of the final score at the 25th trial; 20 trials raise the correlation from .193 to .874. The next 150 trials raise the correlation 13 points. There is no doubt that it is much more difficult to secure this 13-point gain than to secure a 50-point gain in the lower end of the practice period. A gain of one second in a 50-yard dash is enormously difficult to secure.

HOLLINGWORTH suggests that there may have been a change in the nature of the response. "The opposite test after many repetitions comes to resemble color naming; that is, the response becomes more and more intimately associated with the stimulus word." Be this as it may, increase of speed in adding 2 single place digits consists chiefly in (a) using a single fixation pause; the subject perceives the two figures in a single stroke of attention; (b) reducing the duration of the fixation pause; (c) associating these two numbers with one and only one other number—the sum. For example, high speed in adding 5 and 2 consists in perceiving the two figures

in a single fixation pause and immediately calling up 7. The "7" must be most intimately associated with 5 + 2—so close and permanent that the response is immediate. It is possible that some of the 13 subjects, at the beginning of the practice period, fussed and fumbled among several candidates for the sum of this or that group of two digits. Such fumbling among several figures is a sort of pathological condition. If the fumbling does take place, and it undoubtdely does in many individuals, the individual has not learned how to add; for he can never be certain that the sum he selects is the right one. One must associate one figure and only one figure with 5 + 2; the association must be so intimate that the response on perceiving the two figures is instant.

Perhaps some of the 13 subjects, at the beginning of the practice period, used two fixation pauses, one on the 5, for example, and one on the 2. At the end of the practice period they had advanced to a higher level; they perceived the two figures with a single fixation. Given a single fixation pause and one and only one number—the sum—associated with 5 + 2, for example, advance in speed consists in reducing the length of the fixation pause. BUSWELL gives some figures on the duration of the fixation pause in adding several single place numbers. In one case the duration of the pauses ranged from 7 to 11; in terms of sigma this is 280 to 440 sigma. One may venture the conclusion that when subjects reach a high level of speed in adding two single place numbers, the response is not unlike a reaction time response.

Thus a varied group of more or less interacting factors determines how far any one individual will actually travel on the road from his initial score to maximum ability in speed of performance. Incentive appears to be the most significant factor. In HOLLINGWORTH'S experiment incentive was given adequate attention. In the present group of 80 men many were eager to show what they could do; in them no reversal would ever take place. The stimulus of competition either with themselves or with another acts in only way—a supreme effort to surpass. Other men exhibited a distinct "what's the use" attitude and the "don't care" attitude. Doubtless in other men a reversal would take place during the practice; that is, they would give up all effort; incentive would cease to have any influence. What will happen when these same men are practiced to the limit of their capacity, with ade-

quate attention to the various factors mentioned above? The following is submitted as a tentative conclusion. It seems very likely that after such a period of practice, up to 200 trials or more, the relative position of these men on a scale of speed would be about the same as the present position. Some would rise to new heights; others would occupy a middle position; others would either make no effort at all or after a period of more or less vigorous effort would get discouraged and fall behind.

Is there a general speed capacity? HOLLINGWORTH suggests this. The correlation between addition and color naming at the first trial was .26; at the 205th trial it was .76. The correlation between addition and opposites at the first trial was .23; at the 205th trial, .76. Perhaps these final correlations point to the setting up of a sort of reflexlike movement from receptor organs to effector organs in the different types of functions. In the present experiment, subject number 45 is a good example in support of the notion of a general speed capacity; this man is superior in every test; his superior speed ability is associated with a superior level of intelligence.

If there is such a thing as general speed capacity, it must consist of two more or less independent factors. (1) There is the intrinsic physical speed mechanism; this centers chiefly in the velocity of the nerve impulses. But this intrinsic speed mechanism is and must be the average speed capacity of different parts of the nervous system. For example, the flexor nerve-muscle unit is as much as 4 times more rapid than the extensor nerve-muscle unit—in the same individual. It is possible on the basis of the chronaxie (BOURGUIGNON) to secure the average intrinsic speed capacity in any one individual. (2) There are the various distinctly mental speed factors. These mental factors are not concerned with the slow or rapid transmission of a stimulus from one point to another point within the nervous system; they operate in terms of how long it takes to accomplish a given task. Span of perception is an illustration of a strictly mental speed factor. How far up can this or that individual go in the ability to perceive in a single stroke of attention, or at least in a very limited number of strokes of attention, single letters or single words or single phrases or single sentences or even paragraphs? How far up can he go in perceiving a single figure or two figures or three figures, or even more, in a single stroke of attention?

Is the intrinsic span of perception the same in this individual for different types of material or functions? Does his span of perception differ for different types of function? That is, the individual may vary in his capacity to reach a high level type of reaction; he may have a relatively large span of perception for language units and a relatively small span of perception for numerals. However this may be, it is certainly true that a potential general speed capacity does become differential in a single individual and in different individuals; defects in the amount and quality of the learning appear to be the chief disturbing factor.

CONCLUSIONS

1. An apparatus has been devised which records the latent time in the Achilles tendon reflex.

2. This latent time in the reflex differs in these 80 men, ranging from 32 to 96 sigma.

3. This latent time is the expression of a physical speed mechanism—the velocity of nerve impulses and allied mechanisms; the mechanism governs the time it takes the nervous system to transmit a stimulus from one point to another point.

4. The latent time reveals a certain level of speed in that part of the nervous system which subserves the reflex. The correlation ratio points to a similar level of speed of transmission in other parts of the nervous system of the given individual.

5. In the correlation, the comparison is between a single intrinsic speed mechanism on the one hand and a conglomerate of strictly mental speed factors on the other hand. The physical mechanism governs the quickness of a single movement; the influence of the mental factors centers in the quickness of achievement or performance.

6. These mental speed factors differ in these 80 men; (1) in original endowment; for example, the span of perception may be 3 figures in some men; two figures in other men; and one figure only in some men. (2) These mental speed abilities must be acquired through learning; the present functional efficiency of these mental factors differs very greatly in the different men in consequence of the different amounts of learning and the different qualities of the learning.

7. It appears likely that a period of practice, even a prolonged period with the purpose of reaching the limits of speed in each man, will not greatly alter the present correlation ratio. The relative position of the 80 men on a scale of speed will be about the same as it is at present. The strictly differential effect of incentive appears to be the chief factor in maintaining this same relative position.

8. It seems likely that there is a general speed ability which is more or less intimately associated with the level of intelligence. But the potential ability is one thing; actually setting this ability into action is another thing. The most challenging problem is how to make incentive actually stimulate the given individual so that he eventually does rise to a maximum level of speed.

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ABBREVIATIONS

AJP: American Journal of Physiology.
AJPsy: American Journal of Psychology.
JEdPsy: Journal of Educational Psychology.
JExPsy: Journal of Experimental Psychology.
JAPsy: Journal of Applied Psychology.
PR: Psychological Review.
PRS: Proceedings of Royal Society of London.
TC: Teachers College Contributions to Education.
AP: Archives of Psychology.
JP: Journal of Physiology.
Pflüger: Pflüger's Archiv für die gesamte Physiologie.

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